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Savarese

(10) **Patent No.: US 9,243,843 B2**
(45) **Date of Patent: Jan. 26, 2016**

(54) **DRYING APPARATUS AND METHODS**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 815 days.

(21) Appl. No.: **13/323,657**

(22) Filed: **Dec. 12, 2011**

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(51) **Int. Cl.**
F26B 3/34 (2006.01)
F26B 17/02 (2006.01)
F26B 3/30 (2006.01)

(52) **U.S. Cl.**
CPC ***F26B 17/023*** (2013.01); ***F26B 3/30*** (2013.01)

(58) **Field of Classification Search**
CPC F26B 3/30; F26B 17/023
USPC 34/266, 268, 269, 273, 418–422
See application file for complete search history.

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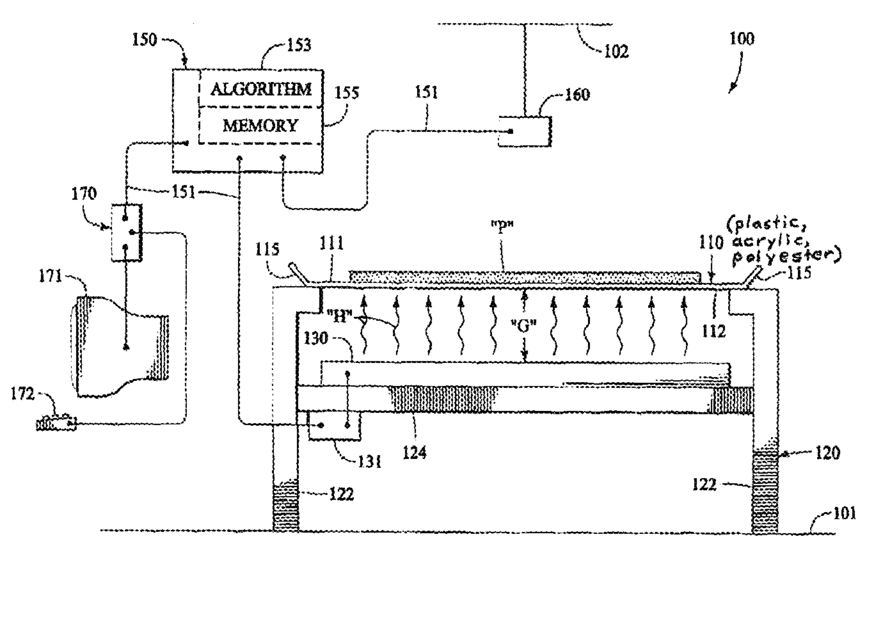
(57) **ABSTRACT**

The present disclosure concerns a drying or heating apparatus that is capable of independently controlling the temperature of the product being heated (e.g., to achieve a desired temperature profile) and the wavelength of the radiation (e.g., to maximize the heat transfer rate). To such ends, a drying apparatus can be provided with one or more heat sources that are movable relative to the product being heated in order to increase or decrease the gap or spacing between the heat source and the product. By adjusting the gap between the product and the heat source, it is possible to control the source temperature in such a manner that produces the desired product temperature and wavelength of radiation.

16 Claims, 17 Drawing Sheets



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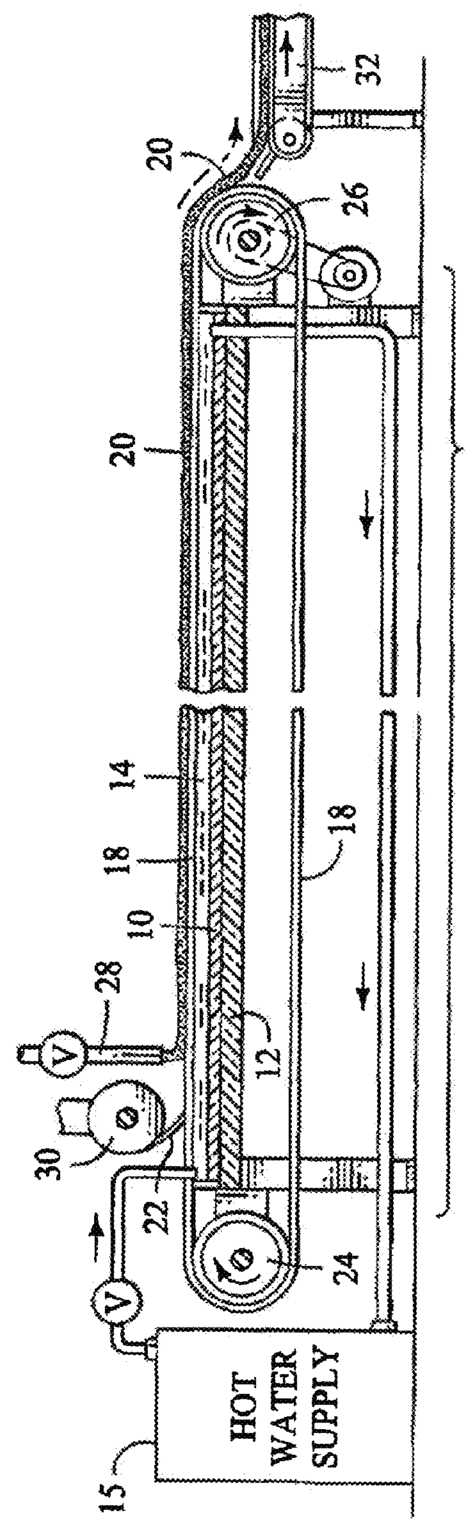

FIG.1
PRIOR ART

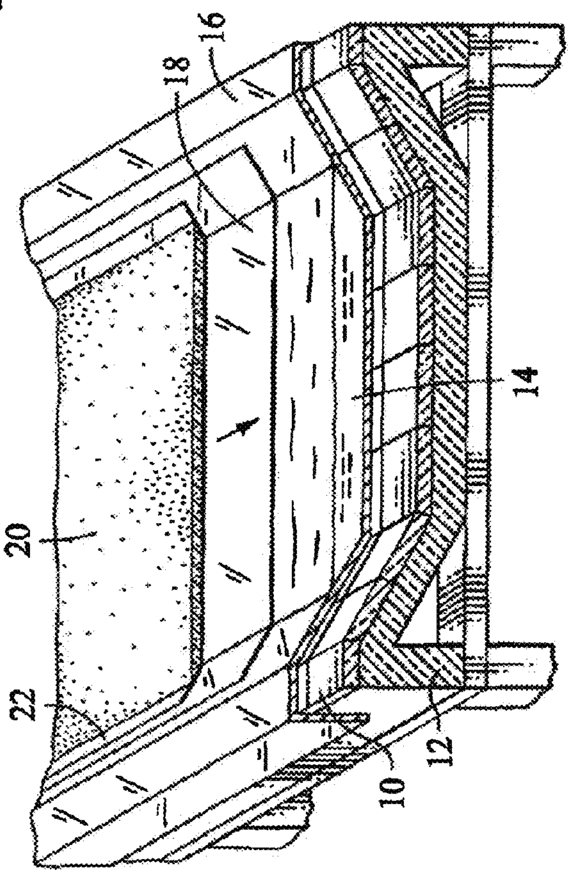

FIG.2
PRIOR ART

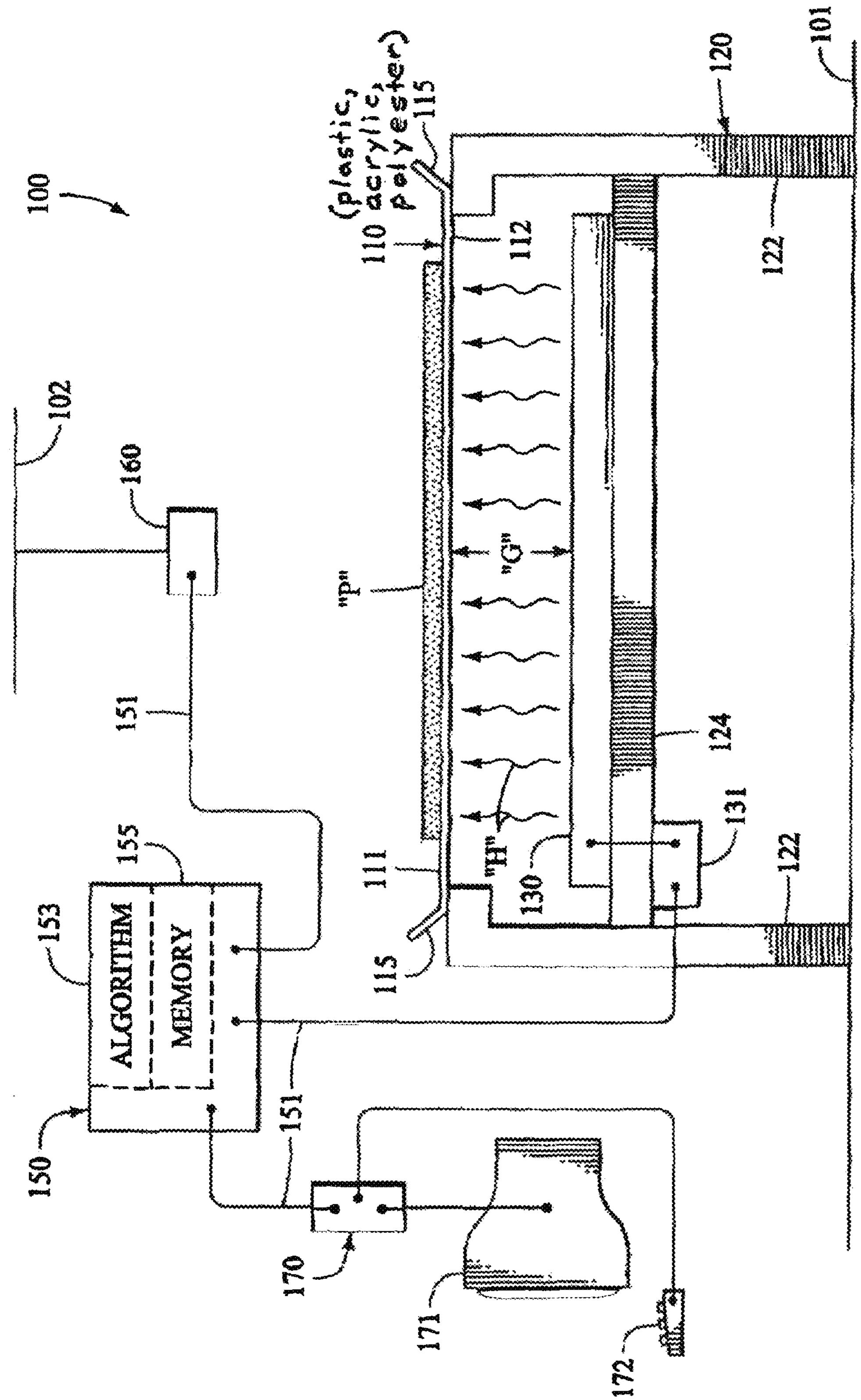
100
102
160
151
155
153
ALGORITHM
MEMORY
150
151
151
170
171
172
"P"
"G"
"H"
110
(plastic, acrylic, polyester)
115
112
111
115
120
101
122
122
124
130
131

FIG.3

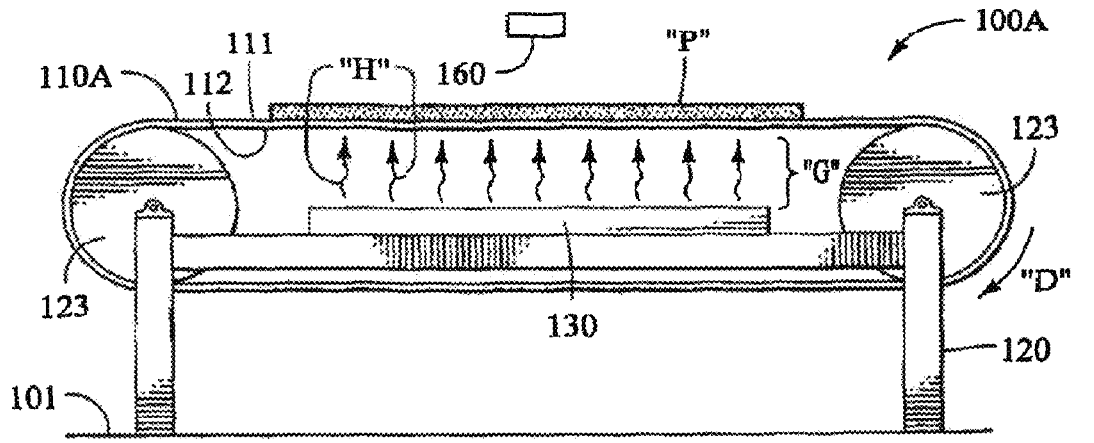

FIG.3A

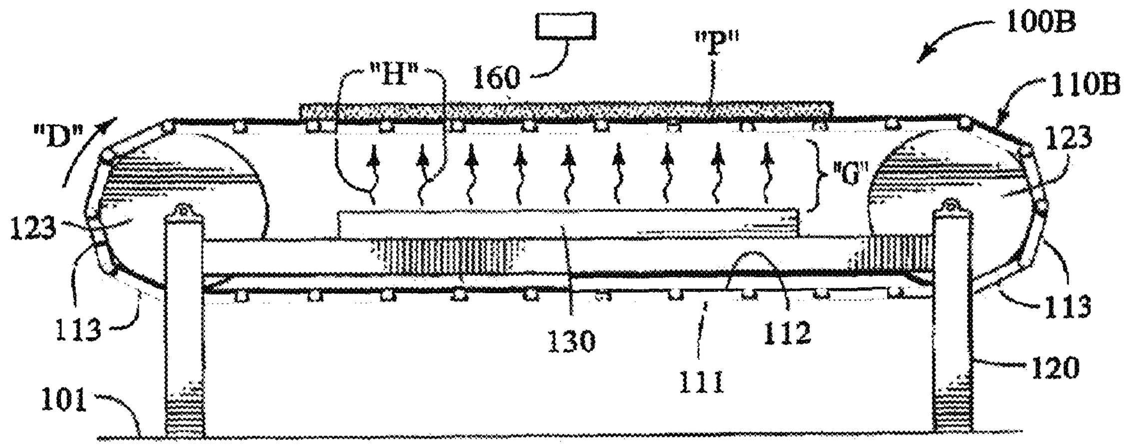

FIG.3B

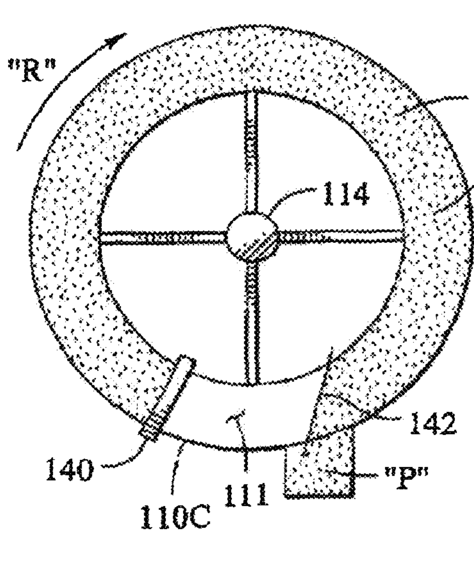

FIG.3C

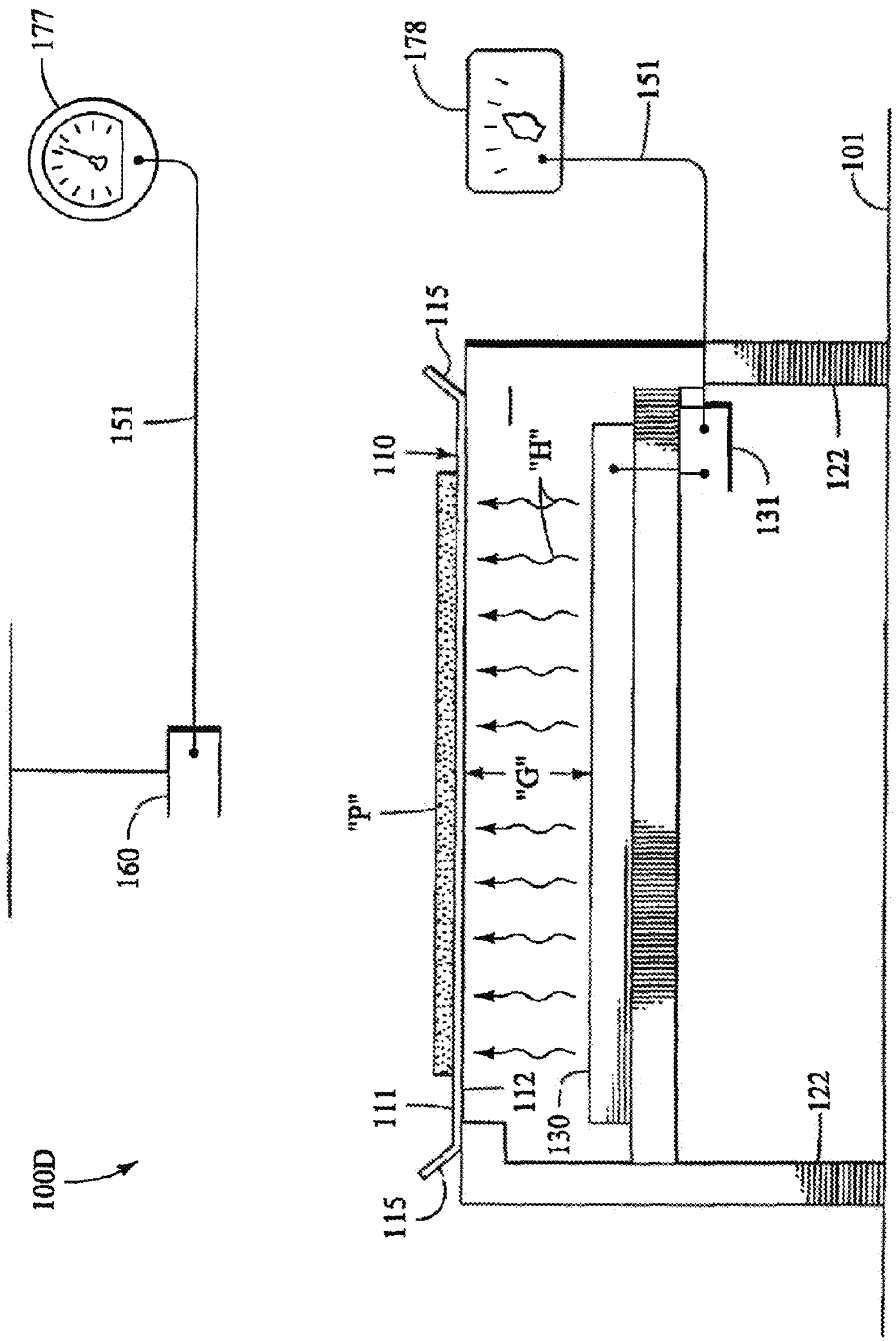

FIG.3D

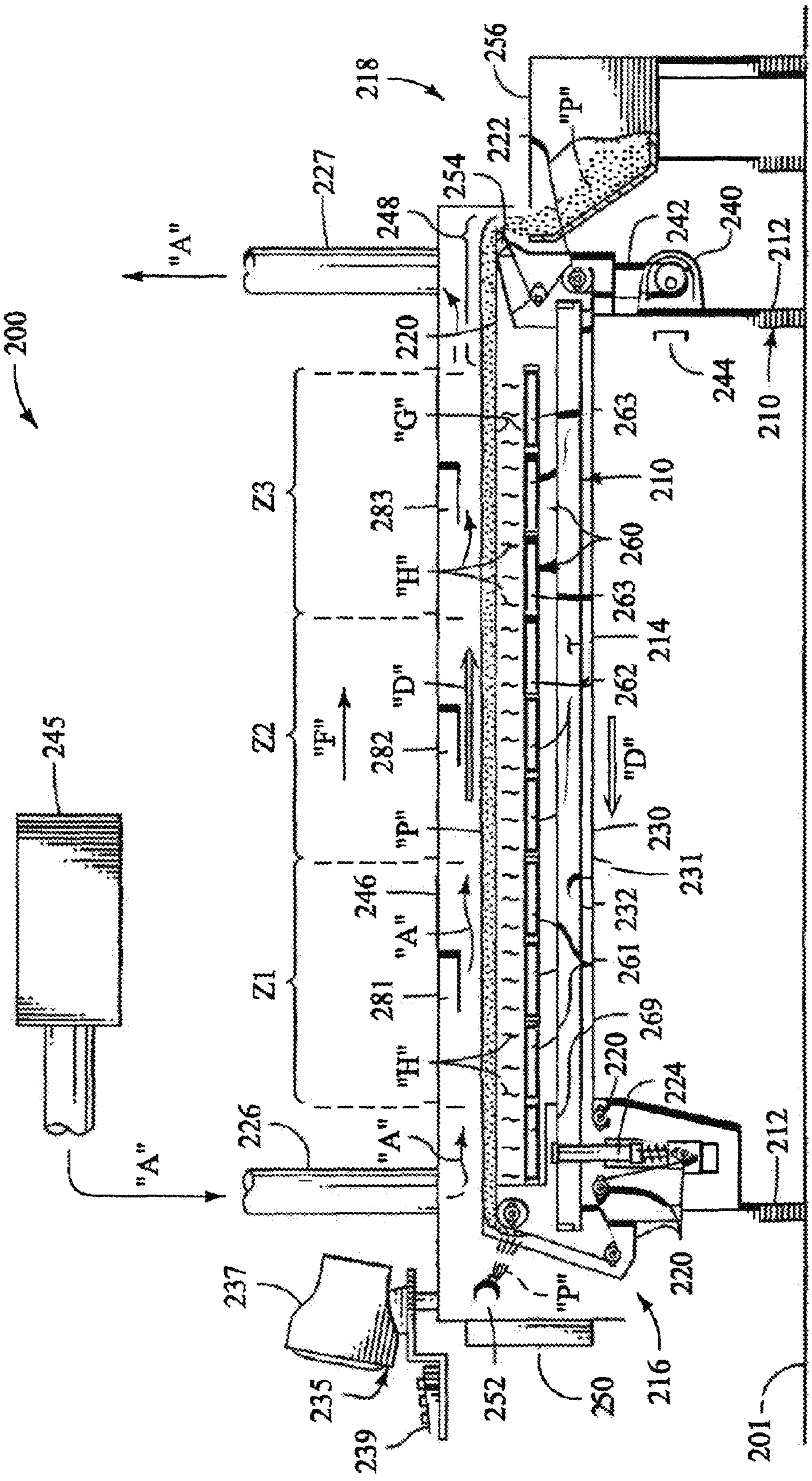
200
218
256
"P"
222
254
248
227
"A"
242
240
212
220
244
210
"G"
263
283
Z3
260
"H"
214
"D"
262
"F"
Z2
282
230
231
"P"
246
232
"A"
261
Z1
281
269
224
226
245
237
235
239
252
250
216
201

FIG.4

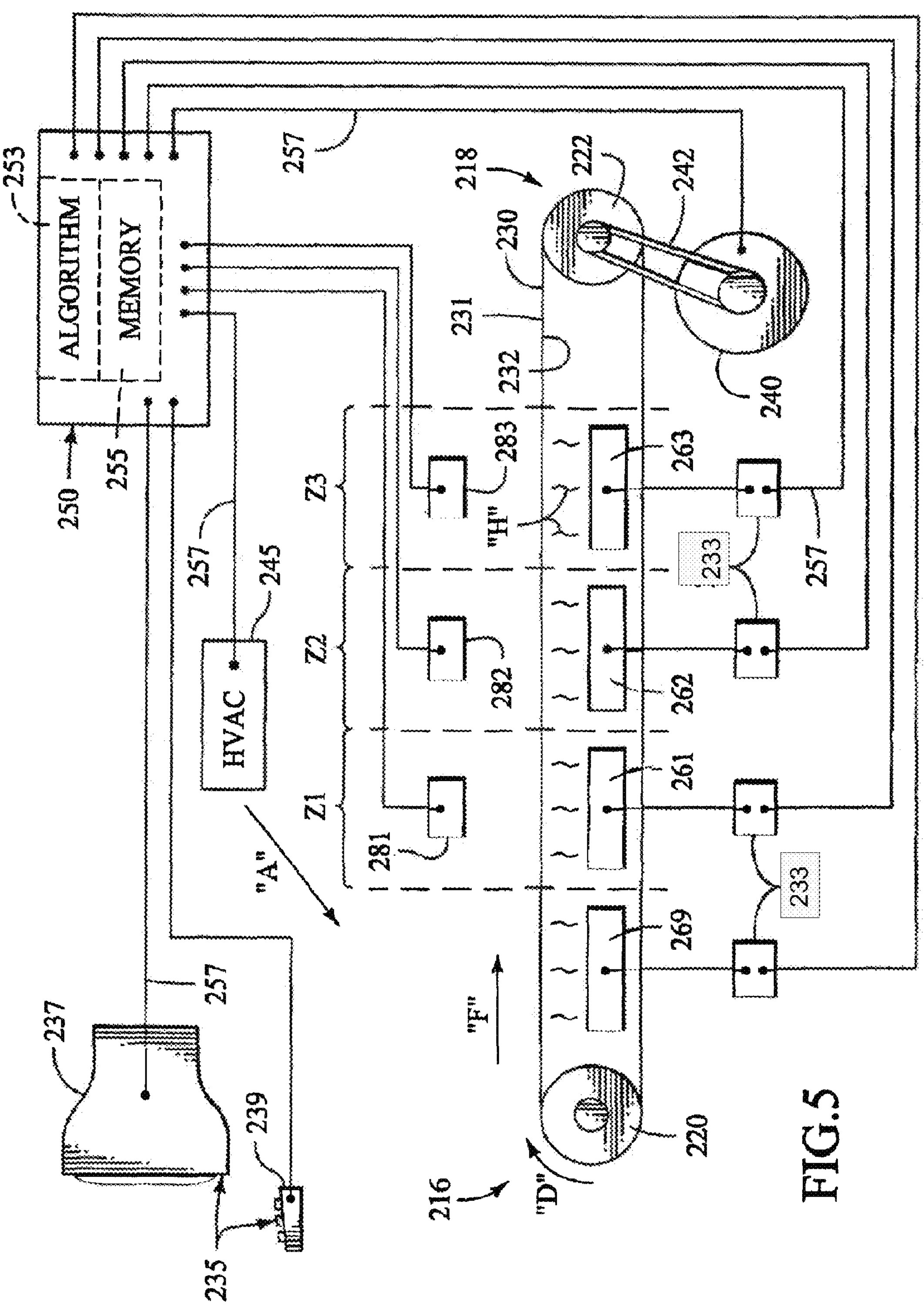
ALGORITHM
MEMORY
HVAC
Z1
Z2
Z3
"A"
"F"
"D"
"H"
216
218
220
222
230
231
232
233
235
237
239
240
242
245
250
253
255
257
261
262
263
269
281
282
283

FIG.5

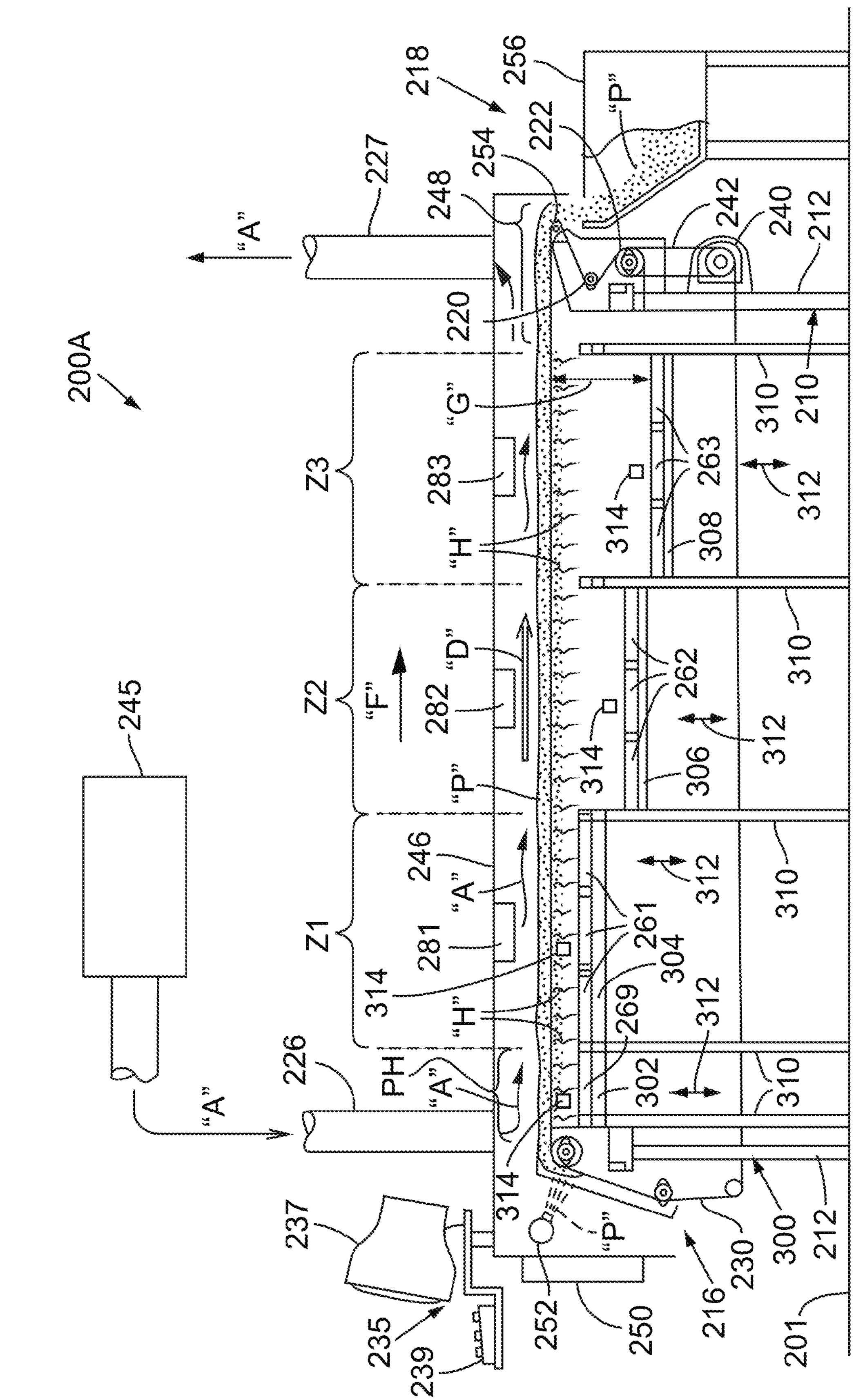
200A
245
"A"
226
237
235
239
250
252
216
230
300
212
201
314
PH
"A"
"H"
Z1
281
246
"A"
261
269
304
302
312
310
Z2
"F"
282
"D"
"P"
262
306
314
Z3
283
"G"
"H"
263
308
210
227
248
254
222
218
256
"P"
242
240
220

FIG. 6

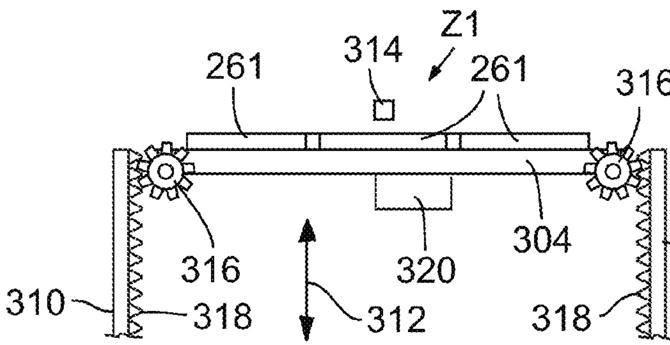
Z1
261
314
261
316
316
320
304
310
310
318
312
318

FIG. 7

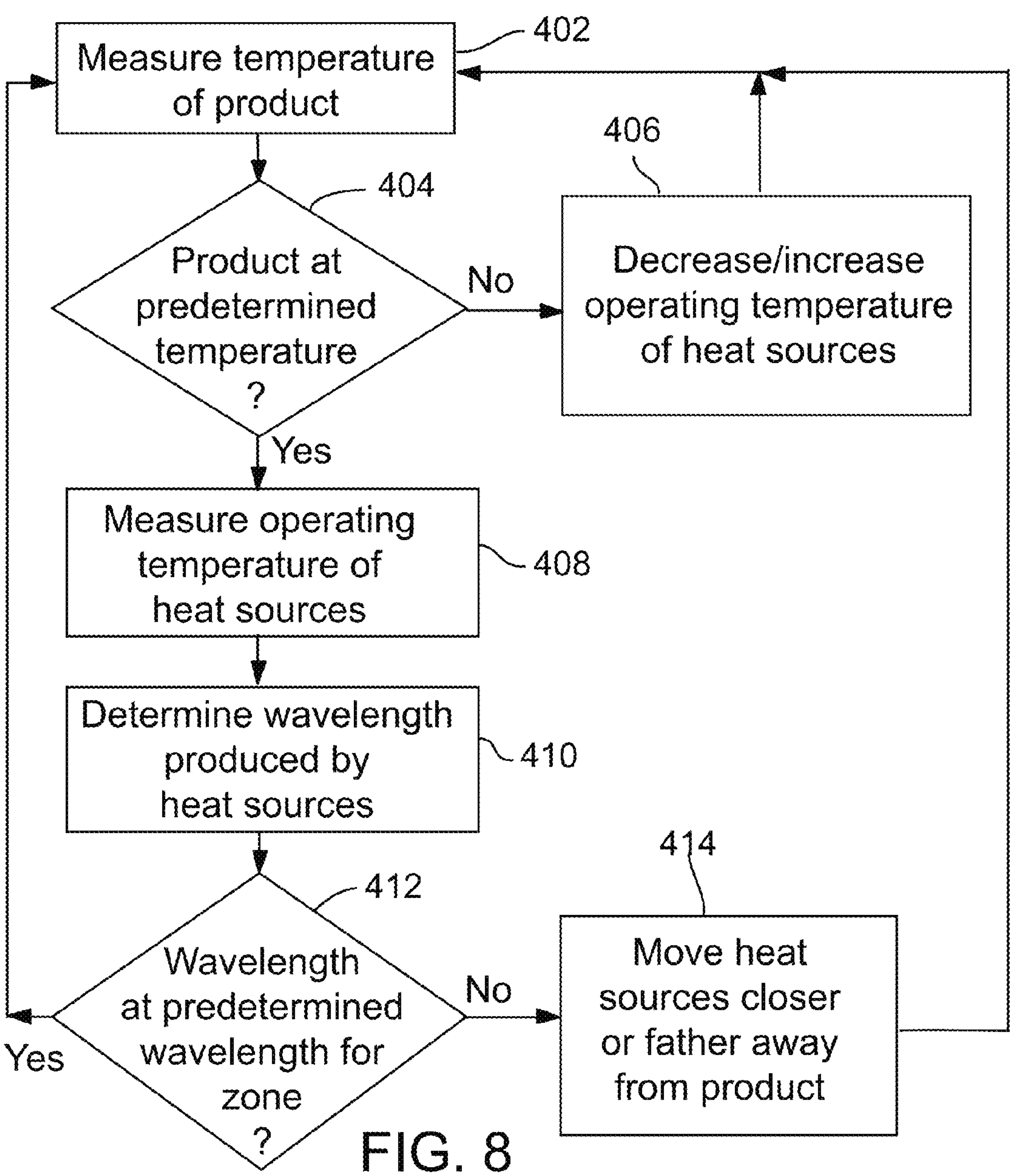
Measure temperature of product
402
404
Product at predetermined temperature ?
No
406
Decrease/increase operating temperature of heat sources
Yes
Measure operating temperature of heat sources
408
Determine wavelength produced by heat sources
410
412
Wavelength at predetermined wavelength for zone ?
No
414
Move heat sources closer or father away from product
Yes

FIG. 8

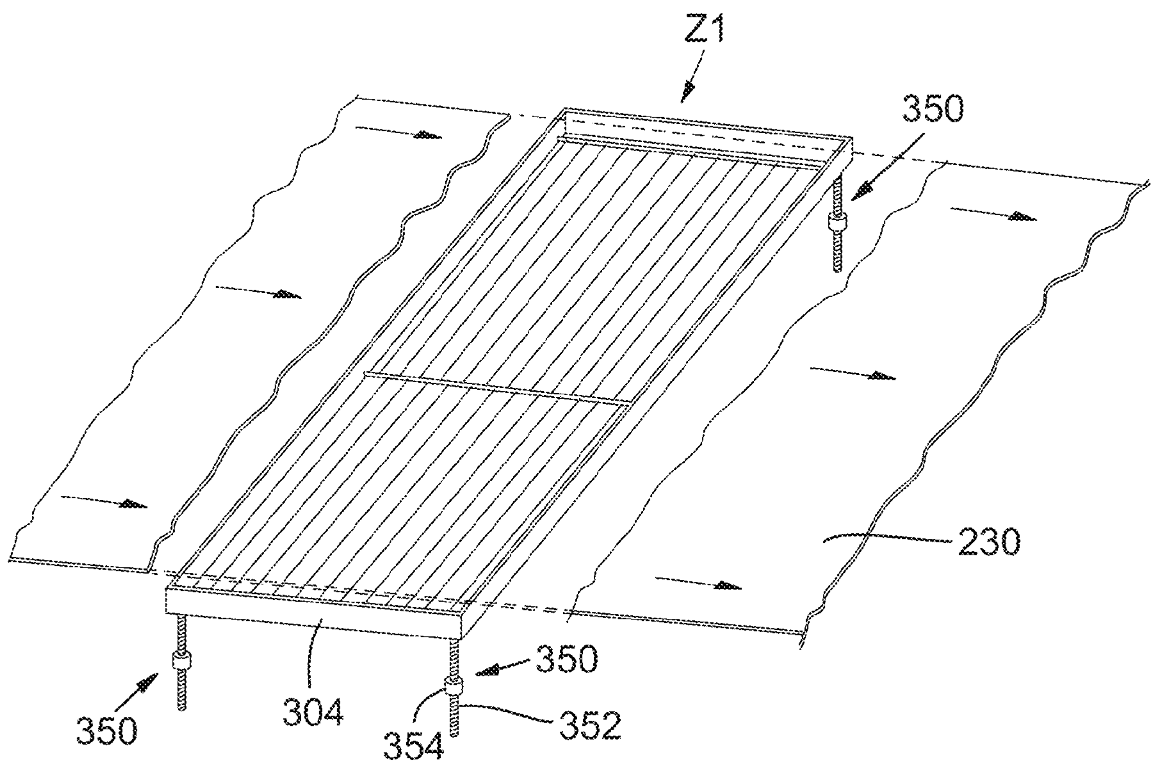

FIG. 9

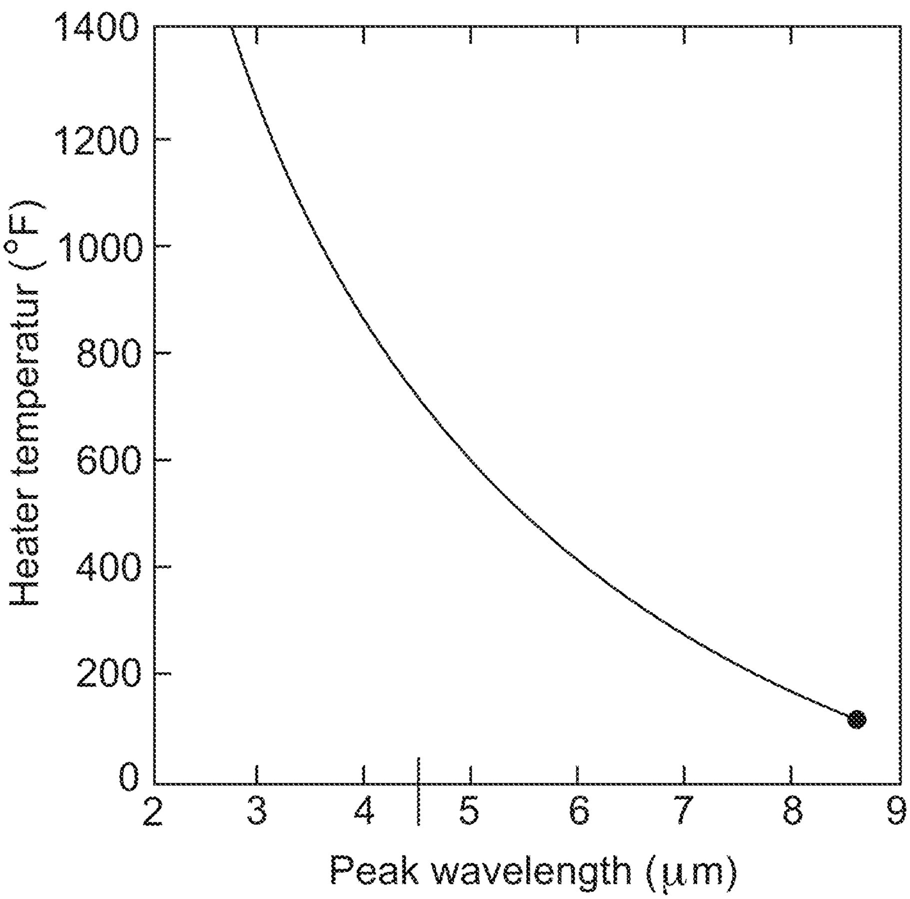
1400
1200
1000
800
600
400
200
0
Heater temperatur (°F)
2
3
4
5
6
7
8
9
Peak wavelength (μm)

FIG. 10

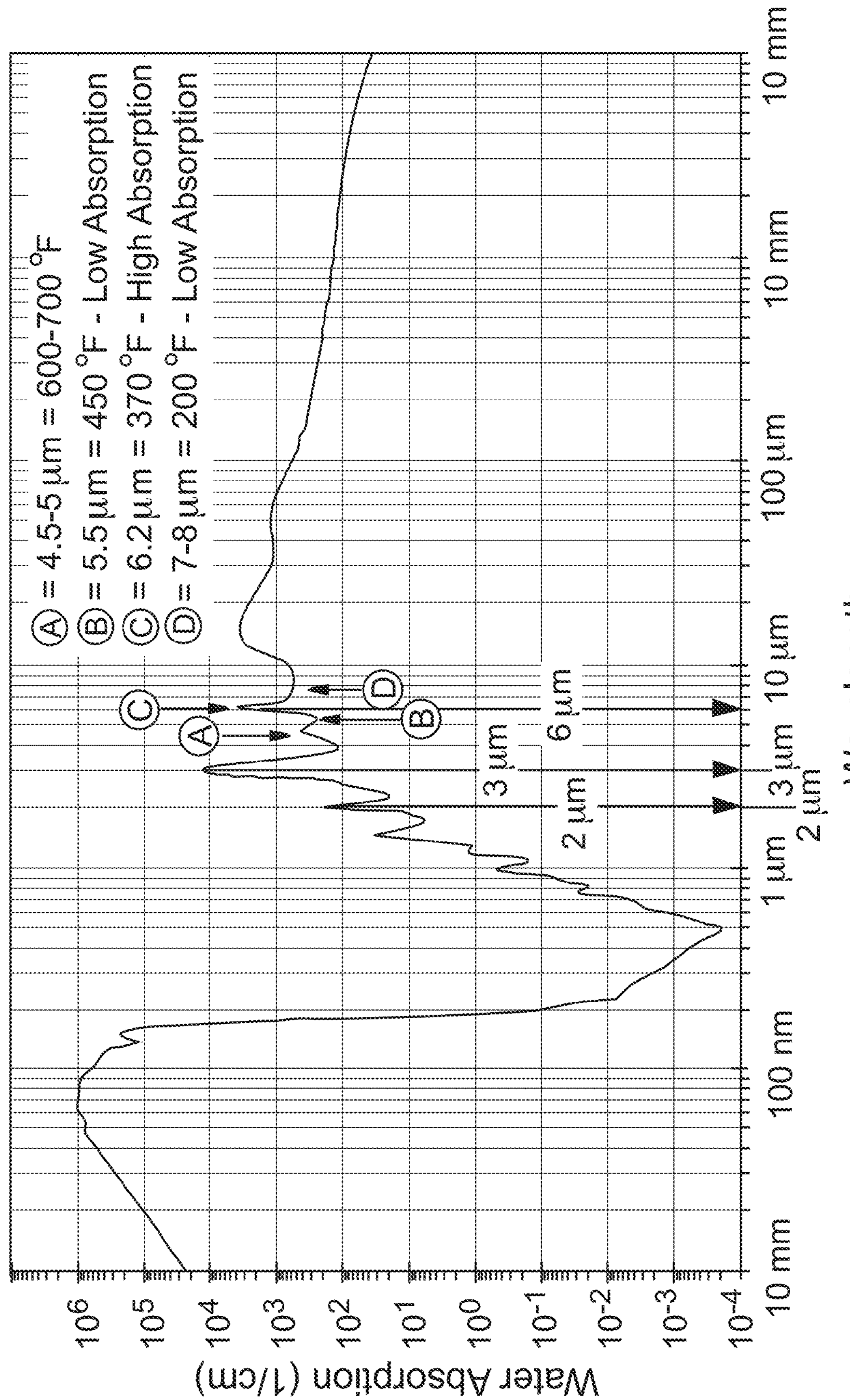
A = 4.5-5 µm = 600-700 °F
B = 5.5 µm = 450 °F - Low Absorption
C = 6.2 µm = 370 °F - High Absorption
D = 7-8 µm = 200 °F - Low Absorption
Water Absorption (1/cm)
10^6
10^5
10^4
10^3
10^2
10^1
10^0
10^-1
10^-2
10^-3
10^-4
10 mm
100 nm
1 µm
10 µm
100 µm
10 mm
10 mm
2 µm
3 µm
6 µm
Wavelength

FIG. 11

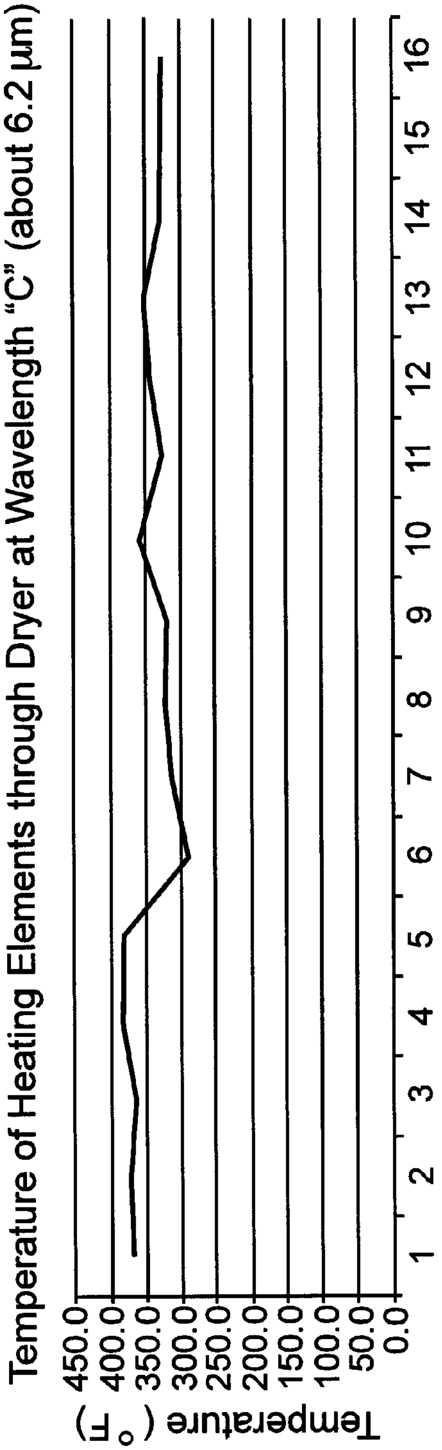
Temperature of Heating Elements through Dryer at Wavelength "C" (about 6.2 μm)
Temperature (° F)
450.0
400.0
350.0
300.0
250.0
200.0
150.0
100.0
50.0
0.0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Zone

FIG. 12

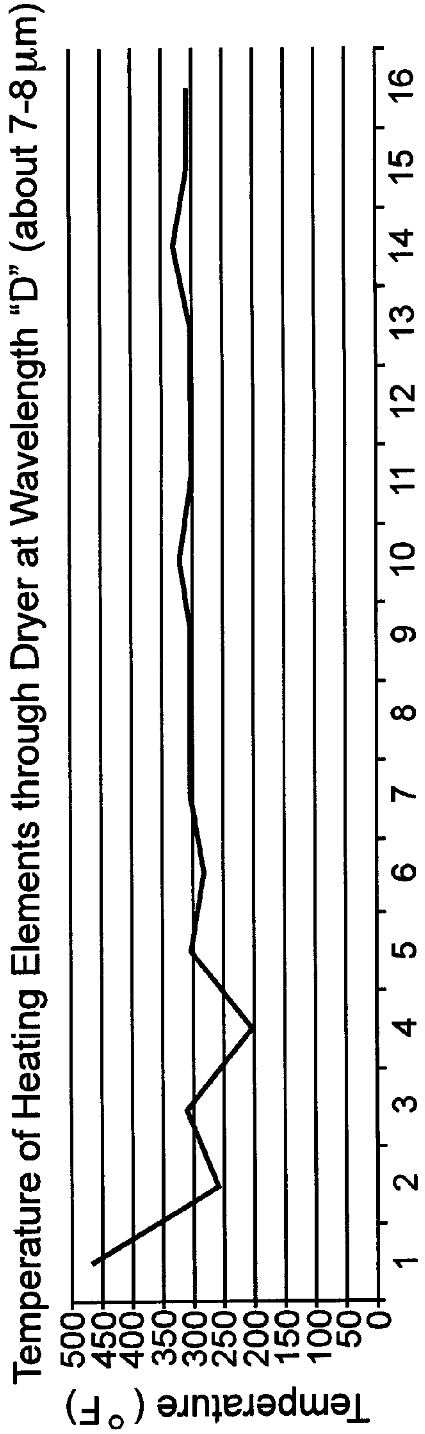
Temperature of Heating Elements through Dryer at Wavelength "D" (about 7-8 μm)
Temperature (° F)
500
450
400
350
300
250
200
150
100
50
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Zone

FIG. 13

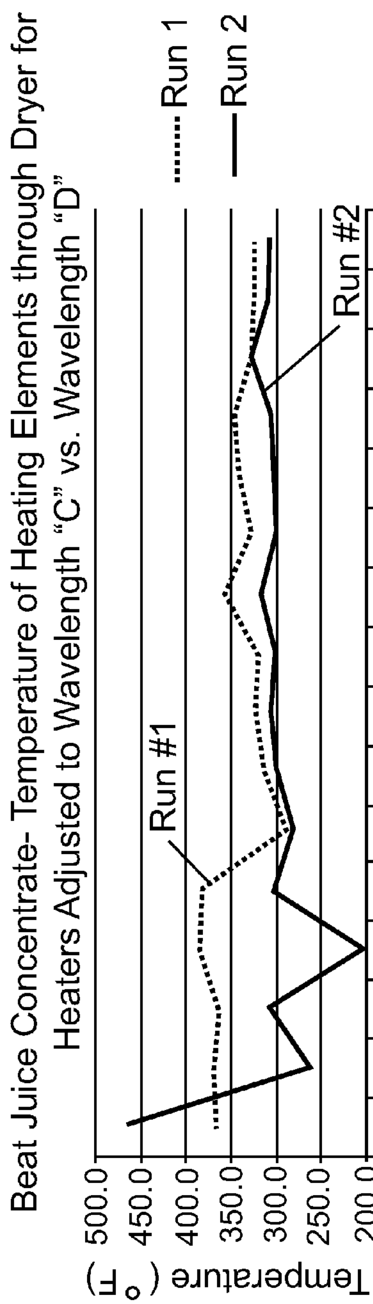
Beat Juice Concentrate- Temperature of Heating Elements through Dryer for Heaters Adjusted to Wavelength “C” vs. Wavelength “D”
Run 1
Run 2
Temperature (° F)
500.0
450.0
400.0
350.0
300.0
250.0
200.0
Zone
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Run #1
Run #2

FIG. 14

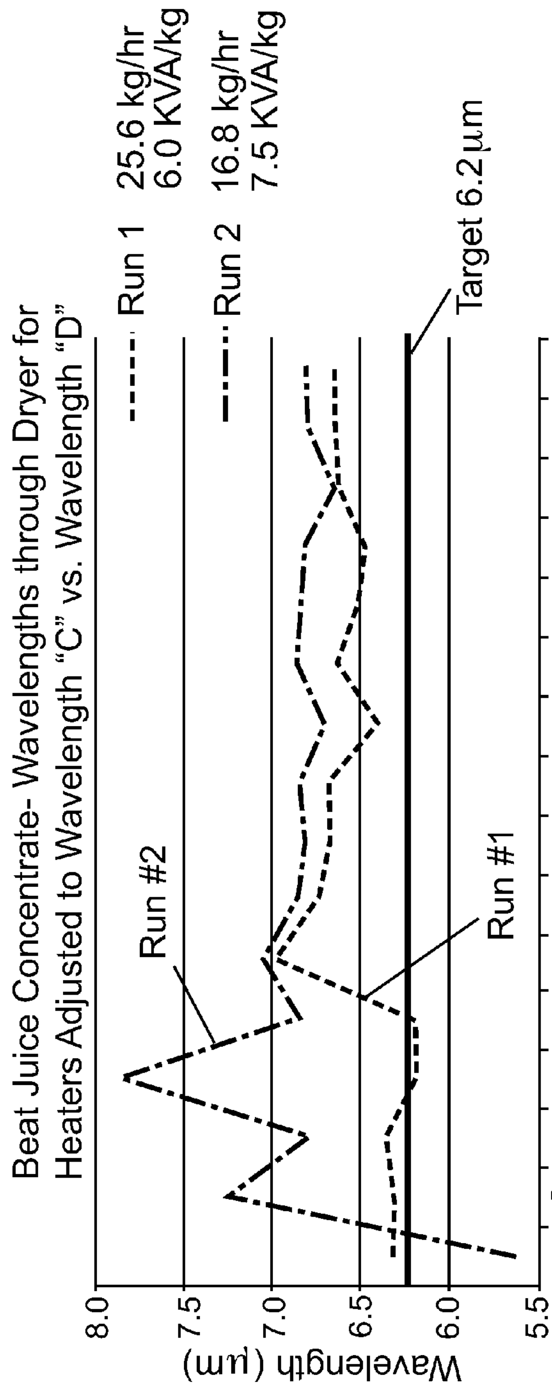
Beat Juice Concentrate- Wavelengths through Dryer for Heaters Adjusted to Wavelength “C” vs. Wavelength “D”
Run 1 25.6 kg/hr 6.0 KVA/kg
Run 2 16.8 kg/hr 7.5 KVA/kg
Target 6.2μm
Wavelength (μm)
8.0
7.5
7.0
6.5
6.0
5.5
Zone
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Run #2
Run #1

FIG. 15

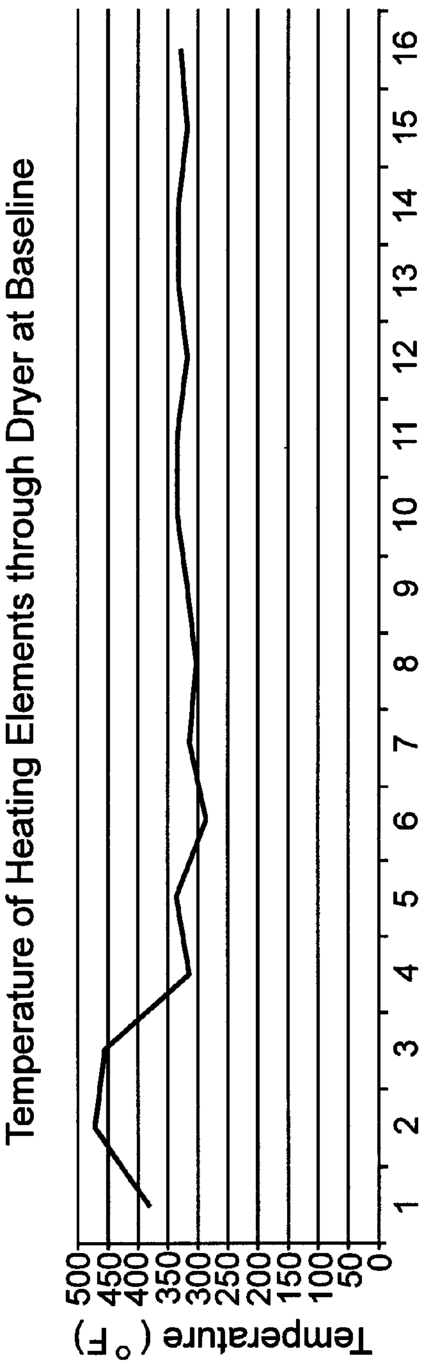
Temperature of Heating Elements through Dryer at Baseline
Temperature (° F)
500
450
400
350
300
250
200
150
100
50
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Zone

FIG. 16

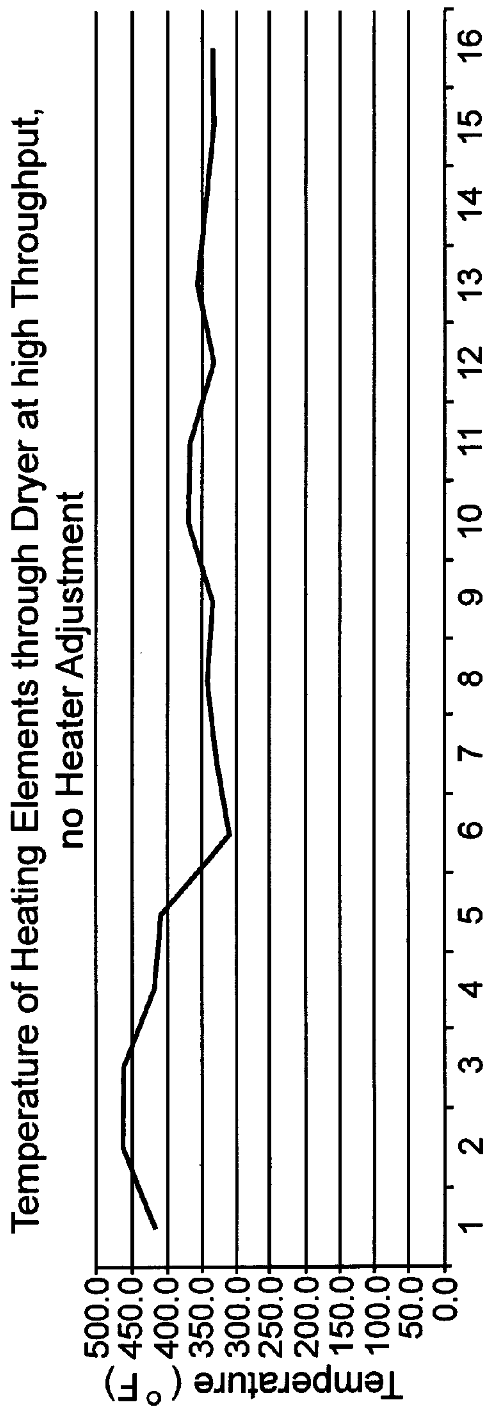
Temperature of Heating Elements through Dryer at high Throughput, no Heater Adjustment
Temperature (° F)
500.0
450.0
400.0
350.0
300.0
250.0
200.0
150.0
100.0
50.0
0.0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Zone

FIG. 17

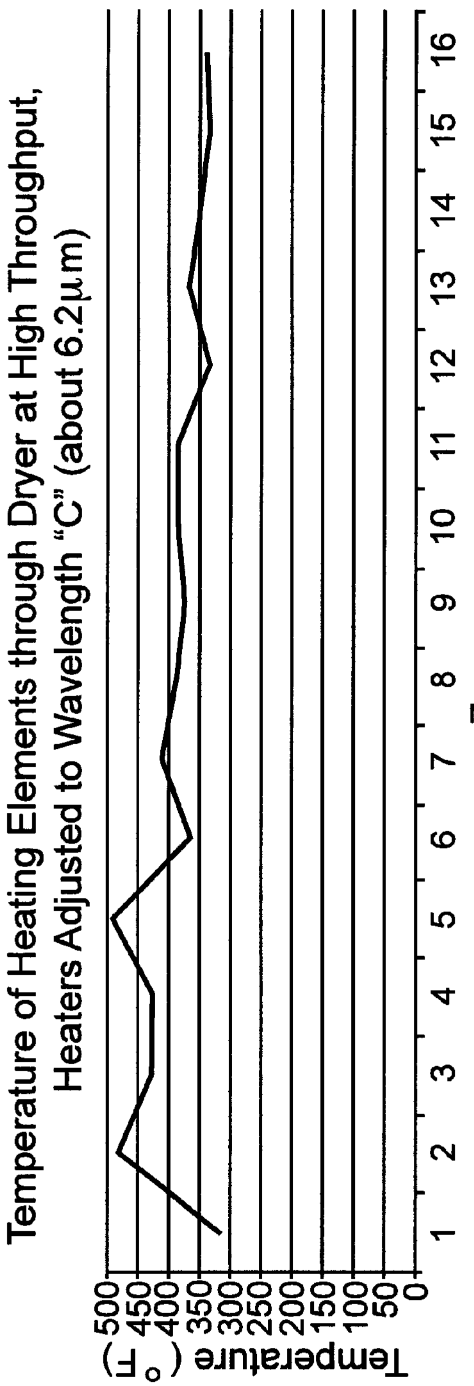
Temperature of Heating Elements through Dryer at High Throughput,
Heaters Adjusted to Wavelength "C" (about 6.2μm)
Temperature (° F)
500
450
400
350
300
250
200
150
100
50
0
Zone
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16

FIG. 18

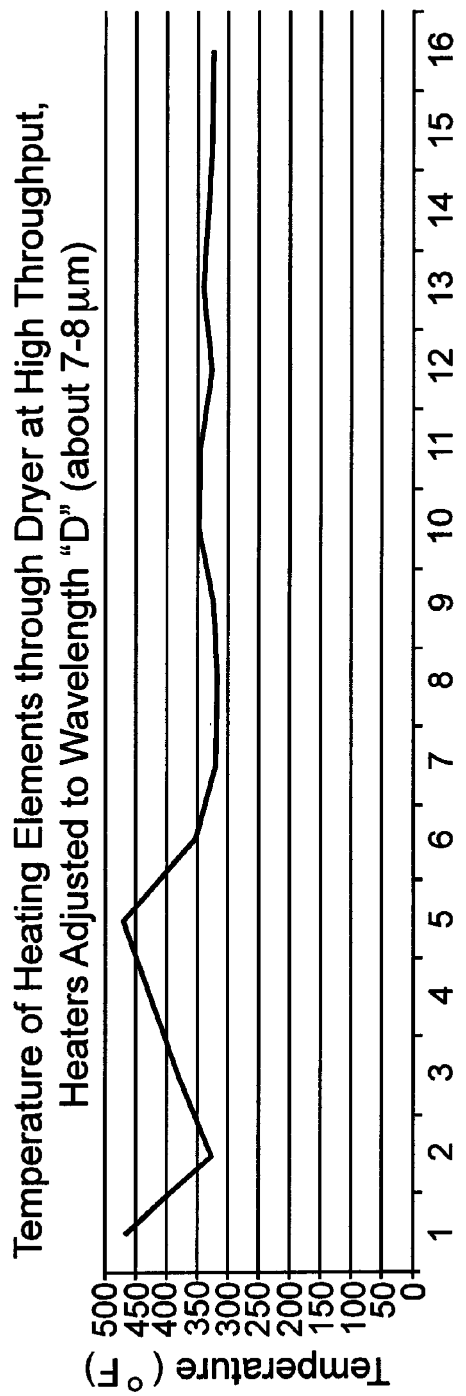
Temperature of Heating Elements through Dryer at High Throughput,
Heaters Adjusted to Wavelength "D" (about 7-8μm)
Temperature (° F)
500
450
400
350
300
250
200
150
100
50
0
Zone
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16

FIG. 19

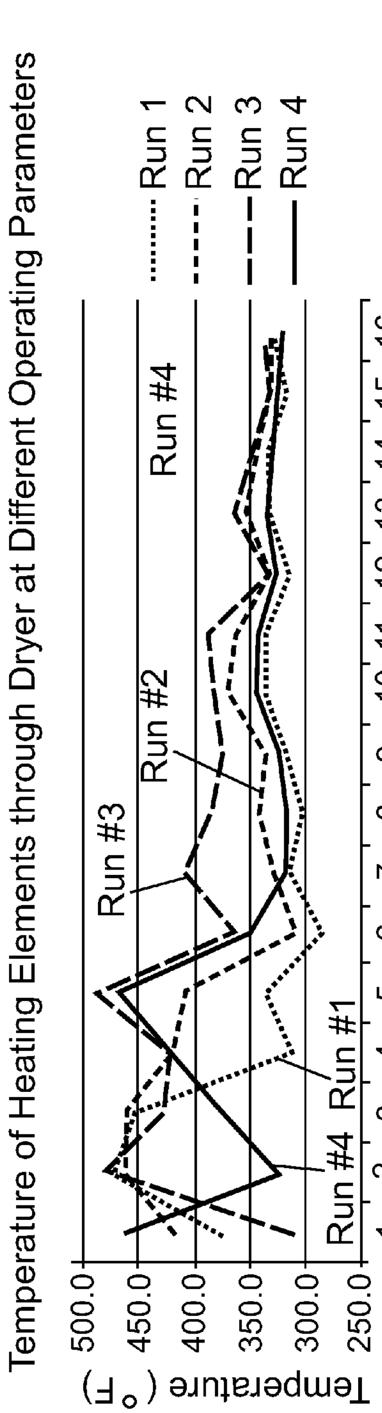
Temperature of Heating Elements through Dryer at Different Operating Parameters
Temperature (° F)
500.0
450.0
400.0
350.0
300.0
250.0
Zone
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Run #1
Run #2
Run #3
Run #4
Run 1
Run 2
Run 3
Run 4

FIG. 20

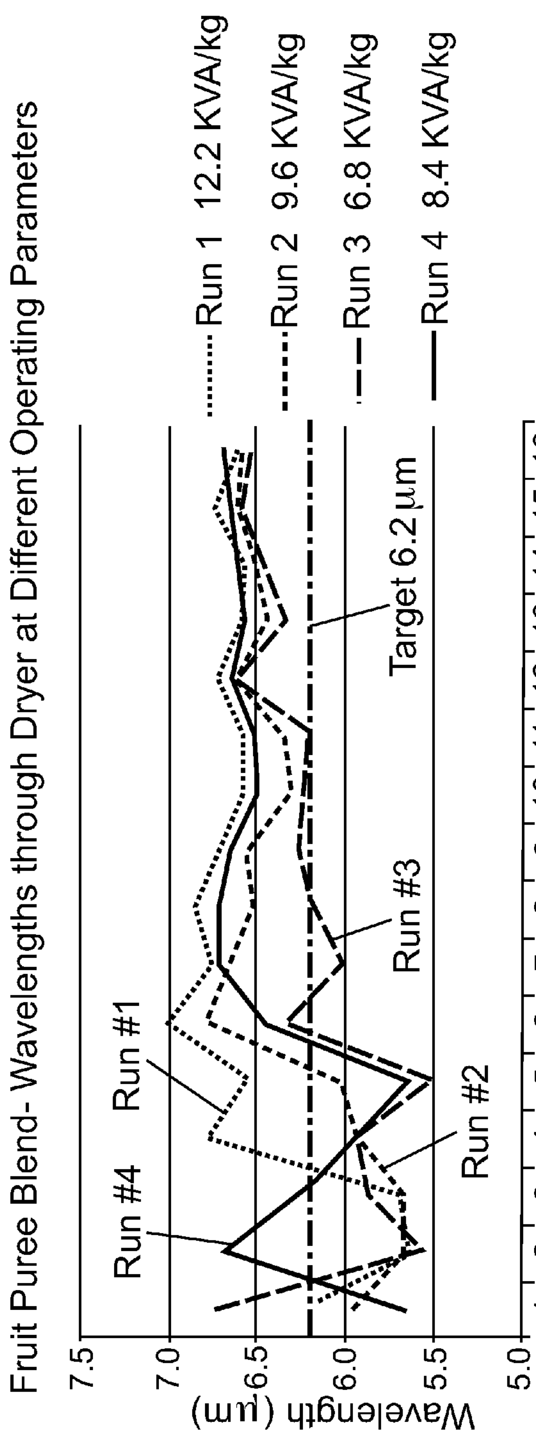
Fruit Puree Blend- Wavelengths through Dryer at Different Operating Parameters
Wavelength (μm)
7.5
7.0
6.5
6.0
5.5
5.0
Zone
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Run #1
Run #2
Run #3
Run #4
Target 6.2 μm
Run 1 12.2 KVA/kg
Run 2 9.6 KVA/kg
Run 3 6.8 KVA/kg
Run 4 8.4 KVA/kg

FIG. 21

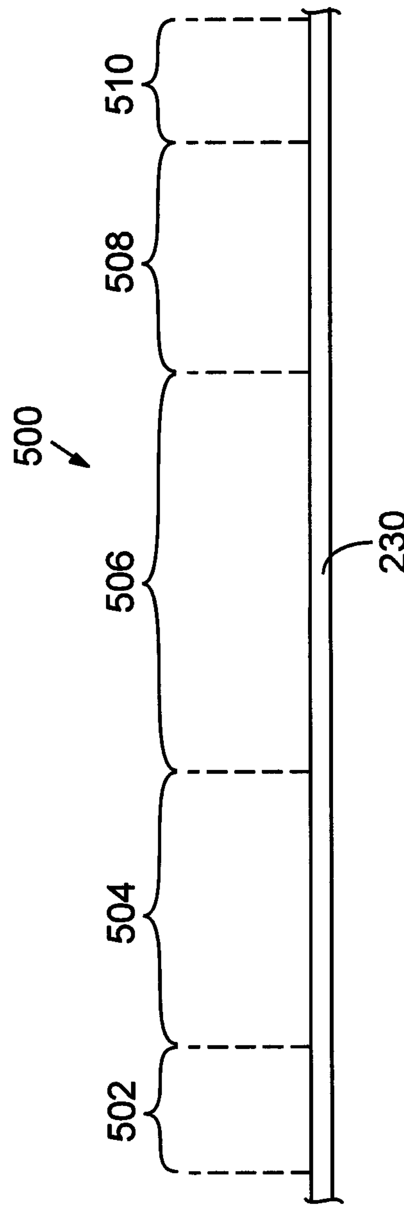

FIG. 22

DRYING APPARATUS AND METHODS

CROSS REFERENCE TO RELATED APPLICATION

The present application claims the benefit of U.S. Provisional Application No. 61/422,076, filed Dec. 10, 2010, which is incorporated herein by reference.

FIELD

The present invention relates to methods and apparatus for drying a product, and more specifically, to methods and apparatus for drying a product which is in the form of a liquid or paste by removing moisture therefrom.

BACKGROUND

Prior art drying apparatus and methods have been utilized for drying organic products which are in the form of liquids or semi-liquids such as solutions and colloidal suspensions and the like. These prior art drying apparatus have been used primarily to produce various dried or concentrated foodstuffs and food-related products, as well as nutritional supplements and pharmaceuticals. The liquid products are usually first processed in a concentrator apparatus which employs a high-capacity heat source, such as steam or the like, to initially remove a portion of the moisture from the suspension. Then, the concentrated products are often processed in a prior art drying apparatus in order to remove a further portion of the remaining moisture.

Various types of prior art drying apparatus have been employed, including spray dryers and freeze dryers. While spray dryers are known to provide high processing capacity at a relatively low production cost, the resulting product quality is known to be relatively low. On the other hand, freeze dryers are known to produce products of high quality, but at a relatively high production cost.

In addition to spray dryers and freeze dryers, various forms of belt dryers have been used. Such prior art drying apparatus generally include an elongated, substantially flat, horizontal belt onto which a thin layer of product is spread. The product is usually either in the form of a concentrated liquid or a semi-liquid paste. As the belt slowly revolves, heat is applied to the product from a heat source. The heat is absorbed by the product to cause moisture to evaporate there from. The dried product is then removed from the belt and collected for further processing, or for packaging, or the like.

A typical prior art apparatus and method is disclosed in U.S. Pat. No. 4,631,837 to Magoon. Referring to FIGS. 1 and 2 of the '837 patent which are reproduced in the drawings which accompany the instant application as Prior Art FIGS. 1 and 2, an elongated frame or structure is provided on which an elongated water-tight trough 10 is supported. The trough 10 is preferably made of ceramic tile. An insulation layer 12 is provided on the outer surface of the trough 10. The interior surface of the trough 10 is lined with a thin polyethylene sheet 16. Parallel rollers 24, 26 are provided, with one roller being located at each end of the trough 10. One of the rollers 26 is driven by a motor.

A water heater 15 and circulation system, including a pump and related piping, is also provided with the prior art apparatus of the '837 patent. The water heater 15 is configured to heat a supply of water 14 to just below its boiling point, or slightly less than 100 degrees C. The pump and related piping system is configured to circulate the water 14 through the trough 10 so that a minimum given water depth is maintained throughout the trough. In addition, the water heater 15 and related circulation system is configured to maintain the water supply within the trough at a temperature which is slightly less than 100 degrees C.

A flexible sheet of polyester, infra-red transparent material 18 in the form of an endless belt is supported about the rollers 24, 26 at each end, and is also supported on top of the water supply 14 within the trough 10. That is, the polyester belt 18 is driven by the roller 26 and revolves there about and the roller 24, while floating on the water 14 within the trough 10. A thin layer of liquid product 20 is dispensed onto the revolving belt 18 by way of a product discharge means 28 which is located at an intake end of the apparatus.

As the layer of product 20 travels along the trough 10 on the belt 18 which floats on the water 14, the product is heated by the water 14 which is maintained near 100 degrees C., and on which the belt 18 floats. The heat from the water 14 drives moisture from the product 20 until the product reaches the desired dryness, whereupon the product is removed from the belt 18. The rate at which the belt 18 moves through the trough 10 can be regulated so that the product 20 will reach its desired dryness at the discharge end of the apparatus where it is removed there from.

Several characteristics of the drying apparatus and method disclosed by the '837 patent lead to inconvenient and troublesome use of the apparatus. For example, the trough 10 of a typical prior art apparatus as disclosed by the '837 patent has a length within the range of 12 to 24 meters or more. As a result, the apparatus occupies a relatively large amount of production space. Also, several potential problems regarding the operation of the prior art apparatus can be attributed to the use of water as a heat source.

For example, the prior art apparatus requires a relatively massive water heating and circulation system 15 for its operation. The water heating and circulation system 15 can prove troublesome in several ways. First, the water heating and circulation system 15 adds complexity to the configuration and construction of the apparatus as well as to its operation. The system 15 incorporates a water heater, a pump, and various pipes and valves which must all be maintained in a relatively leak-proof manner. The required water heating and circulation system 15 can also deter the ease of mobility of the prior art dryer because of the bulky nature of the system and because of the need for a water supply.

Secondly, the water 14, which is maintained below the boiling point can serve as a harbor for potentially dangerous microbial organisms which can cause contamination of the product 20. Thirdly, the presence of a large amount of water 14 can serve to counter the objective of the prior art apparatus which is to remove moisture from the product 20. That is, the water 14, by way of inevitable leaks and evaporation from the trough 10, can enter the product 20 thereby increasing the drying time of the product.

Moreover, because the water 14 is the sole source of heat for drying of the product 20, and because the water temperature is maintained below 100 degrees C., the process of drying of the product 20 is relatively slow. As a universally accepted rule, the quantity of heat transferred between two bodies is proportional to the difference in the temperature of each of the bodies. Also, as a general rule, the moisture contained in the product to be dried must absorb a relatively great amount of energy in order to vaporize. The product 20 initially contains a relatively high amount of moisture when it is initially spread onto the support surface 18. Thus, a relatively high amount of heat energy is required to vaporize the moisture and remove it from the product 18.

However, because the temperature of the water heat source of the prior art apparatus never exceeds 100 degrees C., the difference in the temperatures of the heat source and the product 20 is limited which, in turn limits the transfer of heat to the product. As the product 20 absorbs heat from the heat source, the temperature of the product will rise. This rise in temperature of the product as it travels through the apparatus results in an even lower difference in temperature between the product 20 and heat source which, in turn, further reduces the amount of heat transfer from the heat source to the product. For this reason, the prior art apparatus often requires extended processing times in order to satisfactorily remove moisture from the product 20.

Also, the prior art apparatus and method of the '837 patent does not provide for any flexibility in processing temperatures because the temperature of the heat source cannot be easily changed, if at all. For example, the production of some products can benefit from specific temperature profiles during the drying process. The "temperature profile" of a product refers to the temperature of the product as a function of the elapsed time of the drying process. However, because the temperature of the heat source of the prior art apparatus is not only limited to 100 degrees Centigrade, but also slow to change, the temperature profile of the product cannot be easily controlled, or changed.

Because the prior art apparatus disclosed by the '837 patent employs water as a heat source, and requires a large water heating system for its operation, the resulting prior art apparatus is large, heavy, immobile, complex, difficult to maintain, and can be a source of microbial contamination of the product. Additionally, because the temperature of the water heat source utilized by the prior art method and apparatus is limited to less than 100 degrees Centigrade, the prior art method of drying can be slow and inefficient, and does not provide for modification or close control of the product temperature profile.

Drying systems incorporating infrared heating elements can solve many of the problems of the prior art apparatus of the '837 patent. Such a drying system is disclosed in U.S. Pat. No. 6,539,645, which is incorporated herein by reference.

It is known that the wavelength band emitted from an infrared heater can be controlled by adjusting the temperature of the infrared heater. Increasing the temperature of an infrared heater will produce radiation of shorter wavelengths while decreasing the temperature of an infrared heater will produce radiation of longer wavelengths. Prior techniques for heating certain substances with infrared radiation have included selection of a particular wavelength band of infrared radiation that is most efficiently absorbed by the substance being heated and/or that produces a desired heating effect.

U.S. Pat No. 5,382,441, for example, discloses an infrared heating system for heating baked goods. The '441 patent discloses that known IR food processes control the source temperature of the heaters to adjust the wavelength of the radiation during a baking process. If greater surface heating is required, the source temperature is decreased to produce longer wavelengths that are less capable of penetrating the surface of the product. Conversely, if less surface heating is required, the source temperature is increased to produce wavelengths that are more capable of penetrating the surface of the product.

U.S. Pat. No. 5,974,688 discloses an infrared heating system for drying wastewater sludge. The system disclosed in the '688 patent purportedly maintains the source temperature of infrared heaters at a temperature that produces wavelengths in a range that maximizes the heat transfer rate into wastewater sludge, thereby minimizing drying time.

However, the prior art techniques of the '411 and '688 patents are insufficient for heating and drying applications where it is desirable to precisely control the temperature of the product being dried, for example, to heat the product according to a predetermined temperature profile that produces the best results for a particular product, such as when drying liquid food products. The need to maintain or control the temperature of the product being dried is directly at odds with the need to heat the product with radiation of a particular wavelength, such as to maximize the heat transfer rate. For example, if the product becomes too hot, then the temperature of the heater must be decreased to avoid overheating and/or burning the product, however decreasing the temperature will increase the wavelength of the radiation. Conversely, if the product requires more heat in a short amount of time to avoid underheating the product, then the temperature of the heater must be increased, which will decrease the wavelength of the radiation. As can be appreciated, the prior art techniques of the '411 and the '688 patents sacrifice the ability to control the temperature profile of the product by maintaining the heat sources at predetermined settings that produce radiant heat at the desired wavelength.

SUMMARY

According to one aspect, the present disclosure concerns a drying or heating apparatus that is capable of independently controlling the temperature of the product being heated (e.g., to achieve a desired temperature profile) and the wavelength of the radiation (e.g., to maximize the heat transfer rate). To such ends, a drying apparatus can be provided with one or more heat sources that are movable relative to the product being heated in order to increase or decrease the gap or spacing between the heat source and the product. By adjusting the gap between the product and the heat source, it is possible to control the source temperature in such a manner that produces the desired product temperature and wavelength of radiation.

For example, if a particular drying profile requires that the temperature of the product remain substantially constant through one or more control zones, then the product typically is subjected to less heat in each successive control zone. To maintain the desired product temperature and wavelength of radiation, the heaters in a control zone can be moved farther away from the product to decrease the heat applied to the product while maintaining the source temperature to produce radiation at the desired wavelength. If desired, the source temperature and heater positions can be controlled to produce a predetermined constant wavelength in successive zones and to heat the product at the desired temperature profile to compensate for changes in energy required to evaporate moisture as the moisture content in the product decreases as it is dried through each of the zones. In other words, unlike the '411 and the '688 patents, the drying apparatus of the present disclosure has the ability to heat a product or object at a predetermined wavelength, such as to maximize heat absorption by the product or object, without sacrificing control over the temperature profile of product or object being heated.

In one representative embodiment, a drying apparatus comprises a movable product conveyor having a product support surface for supporting a product to be dried, at least first and second heater supports, and a controller. Each heater support supports one or more dry radiant heating elements and is movable relative to each other and relative to the conveyor to adjust the distance between each heater support and the conveyor. The product conveyor is configured to move relative to the first and second heater supports such that the product supported on the conveyor is successively heated by the heating elements of the first heater support and the heating elements of the second heater supports. The controller is configured to adjust the temperature of the heating elements of each heater support and the distance between the heating elements of each heater support and the conveyor such that the heating elements emit radiant heat at a predetermined wavelength and heat the product according to a predetermined product temperature profile.

In another representative embodiment, a drying apparatus comprises a movable product conveyor having a product support surface for supporting a product to be dried, at least first and second heating zones, and a controller. The conveyor is operable to convey the product through the heating zones. The first heating zone comprises a first set of one or more radiant heating elements mounted underneath the product support surface for movement upwardly and downwardly relative to the product support surface. The second heating zone comprises a second set of one or more radiant heating elements mounted underneath the product support surface for movement upwardly and downwardly relative to the product support surface. The controller is configured to continuously monitor the wavelength of the heating elements in each zone and the product temperature in each zone and to adjust the temperature of the heating elements in each zone and the distance between the heating elements of each zone and the conveyor such that the heating elements emit radiant heat at a predetermined wavelength in each zone and heat the product according to a predetermined product temperature profile.

In another representative embodiment, a method of drying a product comprises applying a product to be dried onto a product support surface of a movable conveyor; conveying the product on the conveyor through at least a first heating zone and a second heating zone; and heating the product with a first set of one or more dry radiant heating elements in the first heating zone and heating the product with a second set of one or more dry radiant heating elements in the second heating zone. As the conveyor conveys the product through the first and second heating zones, the temperature of the heating elements and the distance between each set of heating elements and the product support surface are adjusted so as to heat the product at a predetermined temperature profile and to cause the heating elements to emit radiant heat at a predetermined wavelength.

The foregoing and other features and advantages of the invention will become more apparent from the following detailed description, which proceeds with reference to the accompanying figures.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a side elevation diagram of a prior art apparatus.

FIG. **2** is a partial perspective of the prior art apparatus depicted in FIG. **1**.

FIG. **3** is a side elevation diagram of an apparatus in accordance with a first embodiment of the present disclosure.

FIG. **3**A is a side elevation diagram of an apparatus in accordance with a second embodiment.

FIG. **3**B is a side elevation diagram of an apparatus in accordance with a third embodiment.

FIG. **3**C is a top plan view of an apparatus in accordance with a fourth embodiment.

FIG. **3**D is a side elevation diagram of a fifth embodiment showing an alternative operational control scheme for the apparatus depicted in FIG. **3**

FIG. **4** is a side elevation diagram of an apparatus in accordance with a sixth embodiment.

FIG. **5** is a schematic diagram showing one possible configuration of communication links between the various components of the apparatus depicted in FIG. **4**.

FIG. **6** is a side elevation diagram of an apparatus in accordance with an eighth embodiment.

FIG. **7** is an enlarged, schematic side elevation diagram of one of the movable heater supports of the apparatus depicted in FIG. **6**.

FIG. **8** is a flowchart illustrating a method for operating the drying apparatus shown in FIG. **6**.

FIG. **9** is a perspective, schematic view of a movable heater support, according to another embodiment.

FIG. **10** is a line graph showing the relationship between the operating temperature of a quartz heating element and the peak wavelength of infrared radiation emitted by the heating element.

FIG. **11** is a chart showing the absorption of electromagnetic radiation by water across a range of wavelengths.

FIGS. **12-14** show the temperature of the heating elements in each zone of a dryer under different operating conditions for dehydrating beet juice concentrate.

FIG. **15** shows the wavelength of infrared radiation measured in each zone of a dryer under different operating conditions for dehydrating beet juice concentrate.

FIGS. **16-20** show the temperature of the heating elements in each zone of a dryer under different operating conditions for dehydrating a fruit puree blend.

FIG. **21** shows the wavelength of infrared radiation measured in each zone of a dryer under different operating conditions for dehydrating a fruit puree blend.

FIG. **22** is a schematic illustration of a drying apparatus, according to another embodiment.

DETAILED DESCRIPTION

The present disclosure provides for methods and apparatus for drying a product containing moisture. The apparatus generally includes a support surface which is substantially transparent to radiant heat. The product is supported on a first side of the support surface or conveyor while radiant heat is directed toward a second side of the support surface to heat the product for drying. The apparatus can also generally include a sensor which is configured to detect and measure at least one characteristic of the product, such as temperature or moisture content. The measurement of the product characteristic can be used to regulate the temperature of the heat source so as to radiate a desired quantity of heat to the product.

The drying methods and apparatus disclosed herein are particularly useful for dehydrating liquid or vegetable liquids (such as juices, purees, pulps, extracts, etc.) and other plant matter. Such substances can be dehydrated to a moisture content below 5%, typically about 3.0%, all while substantially preserving full nutrition and flavor. Due to the extremely low moisture content, the dehydrated liquids (or other dehydrated product) can be milled into powders that are free flowing and shelf stable. The powders can be used in a variety of food-related products, nutraceuticals and pharmaceuticals.

Embodiments of Drying Apparatus

Referring to FIG. **3**, a side elevation view of a basic drying apparatus **100** in accordance with a first embodiment of the present disclosure is depicted. The drying apparatus **100** is generally configured to remove a given amount of moisture from a product "P" to dry or concentrate the product. The product "P" can be in any of a number of types, including aqueous colloidal suspensions, or the like, which can be in the form of a liquid or paste, and from which moisture is to be removed there from by heating. The product "P" is generally spread, or otherwise placed, onto the apparatus **100** for drying. Once the product "P" has reached the desired dryness, it is then removed from the apparatus **100**.

The apparatus comprises a support surface **110** onto which the product "P" is placed for drying. The support surface **110** has a first side **111** which is configured to support a layer of the product "P" thereon as shown. The support surface also has second side **112** which is opposite the first side **111**. Preferably, the first side **111** is substantially flat and supported in a substantially horizontal manner so that, in the case of a liquid product "P," a substantially even layer thereof is formed on the first side. In addition, lips **115** can be formed on the edges of the support surface **110** for the purpose of preventing the product "P" from running off the first side **111** of the support surface.

The support surface **110** can be configured as a substantially rigid tray or the like as shown. However, in an alternative embodiment of the present invention which is not shown, the support surface **110** can be a relatively thin, flexible sheet which is supported by a suitable support system or the like. The support surface **110** is configured to allow radiant heat to pass there through from the second side **112** to the first side **111**. The term "radiant heat" means heat energy which is transmitted from one body to another by the process generally known as radiation, as differentiated from the transmission of heat from one body to another by the processes generally known as conduction and convection.

The support surface **110** is fabricated from a material which is substantially transparent to radiant heat and also able to withstand temperatures of up to 300 degrees Fahrenheit. Preferably, the support surface **110** is fabricated from a material comprising plastic. The term "plastic" means any of various nonmetallic compounds synthetically produced, usually from organic compounds by polymerization, which can be molded into various forms and hardened, or formed into pliable sheets or films.

More preferably, the support surface **110** is fabricated from a material selected from the group consisting of acrylic and polyester. Such materials, when utilized in the fabrication of a support surface **110**, are known to have the desired thermal radiation transmission properties for use in the present invention. Further, plastic resins can be formed into a uniform, flexible sheet, or into a seamless, endless belt, which can provide additional benefits.

Also, such materials are known to provide a smooth surface for even product distribution, a low coefficient of static friction between the support surface **110** and the product "P" supported thereon, flexibility, and resistance to relatively high temperatures. In addition, such materials are substantially transparent to radiant heat, have relatively high tensile strengths, and are relatively inexpensive and easily obtained.

The apparatus **100** can also comprise a chassis **120**. The chassis is preferably rigidly constructed and can include a set of legs **122** which are configured to rest on a floor **101** or other suitable foundation, although the legs can also be configured to rest on bare ground or the like. The chassis **120** can also include a bracket **124**, or the like, which is configured to support thereon a dry radiant heat source **130** which is exposed to the second side **112** of the support surface **110**.

The term "exposed to" means positioned such that a path, either direct or indirect, can be established for the transmission of radiant heat energy, wave energy, or electromagnetic energy between two or more bodies. The heat source **130** is configured to direct radiant heat "H" across a gap "G" and toward the second side **112** of the support surface **110**.

The term "dry radiant heat source" means a device which is configured to produce and emit radiant heat, as well as direct the radiant heat across a gap to another body, without the incorporation or utilization of any liquid heating medium or substance of any kind, including water. The term "gap" means a space which separates two bodies between which heat is transferred substantially by radiation and wherein the two bodies do not contact one another.

Since the apparatus **100** does not employ water, or other liquid, as a heating source or heating medium, the apparatus **100** is greatly simplified over prior art apparatus which do employ liquid heating media. In addition, the absence of a liquid heat medium in the apparatus **100** provides additional benefits.

For example, the absence of a water heating medium decreases likelihood of microbial contamination of the product "P" as well as the likelihood of re-wetting the product. Moreover, the absence of liquid heating medium and associated heating/pumping system enables the apparatus **100** to be moved and set up relatively easily and quickly which can provide benefits in such applications as on-site field harvest/processing.

The dry radiant heat source **130** is preferably configured to direct radiant heat "H" toward the second side **112** of the support surface **110**. Preferably, the dry radiant heat source **130** is positioned relative to the support surface **110** such that the second side **112** thereof is directly exposed to the radiant heat source. However, in an alternative embodiment of the present invention which is not shown, reflectors or the like can be employed to direct the radiant heat "H" from the radiant heat source **130** to the second side **112** of the support surface **110**. Also, although it is preferable for the heat source **130** to be positioned so as to direct heat "H" toward the second side **112**, it is understood that the heat source can be positioned so as to direct heat toward the first side **111**, and thus directly at the product "P" in accordance with other alternative embodiments of the present invention which are not shown.

Preferably, the radiant heat source **130** is configured to operate using either electrical power or gas. The term "gas" means any form of combustible fuel which can include organic or petroleum based products or by-products which are either in a gaseous or liquid form. More preferably, the radiant heat source **130** is selected from the group consisting of gas radiant heaters, and electric heaters. The term "gas radiant heaters" means devices which produce substantially radiant heat by combusting gas. The term "electric radiant heaters" means devices which produce substantially radiant heat by drawing electrical current. Various forms of such heaters are known in the art. The use of such heaters as the heat source **130** can be advantageous because of the several benefits associated therewith.

For example, such heaters can attain high temperatures and can produce large quantities of radiant heat energy. Such heaters can attain temperatures of at least 100 degrees Centigrade and can attain temperatures significantly greater than 100 degrees Centigrade. The high temperatures attainable by these heaters can be beneficial in producing large amounts of heat energy. In addition, the temperature of the heater, and thus the amount of radiant heat energy produced, can be relatively quickly changed and can be easily regulated by proportional modulation thereof. Also, such heaters generally tend to be relatively light in weight compared to other heat sources, and are generally resistant to shock and vibration.

Since electric radiant heaters such as quartz heaters and ceramic heaters draw electrical power for operation, such heaters can be operated either from a portable generator, or from a permanent electrical power grid. Similarly, radiant gas heaters can be operated either from a portable gas supply, such as a liquified natural gas tank, or from a gas distribution system such as an underground pipeline system. Furthermore, heaters such as those discussed above are generally known to provide long, reliable operating life and can be serviced easily.

The radiant heat source **130** is preferably configured to reach a temperature greater than 100 degrees, Centigrade, and more preferably, the heat source is configured to reach a temperature significantly greater than 100 degrees, Centigrade, such as 150 degrees, Centigrade. The radiant heat source **130** can be configured to vary the amount of radiant heat that is directed toward the support surface **110**. That is, the radiant heat source **130** can be configured to modulate the amount of heat that it directs toward the support surface **110**.

Preferably, the radiant heat source **130** can be configured modulate so that the temperature thereof can be increased or decreased in a rapid manner. The heat source **130** can be configured to modulate by employing an "on/off" control scheme. Preferably, however, the heat source can be configured to modulate by employing a true proportional control scheme.

To facilitate the operational control of the heat source **130**, the apparatus **100** can include a control device **131** which is connected to the heat source. The control device **131** can be an electrical relay as in the case of an electrically powered heat source **130**. Alternatively, the control device **131** can be a servo valve as in the case of a gas powered heat source **130**.

The support surface **110** can be configured to be movable with respect to the radiant heat source **130**. For example, the support surface **110** can be configured as a movable tray which can be placed onto, and removed from, the chassis **120** as shown in FIG. **3**. In an alternative configuration of the first embodiment of the invention, the chassis **120** can include rollers or the like on which the support surface **110** can be supported and moved.

For example, referring to FIG. **3**A, a side elevation diagram is shown of an apparatus **100**A in accordance with a second embodiment of the present invention. As is evident, the support surface **110**A of the apparatus **100**A is configured as an endless belt comprising a flexible sheet supported by rollers **123**. The support surface **110**A can be configured to move, or circulate, in the direction "D."

The rollers **123** are, in turn, supported by the chassis **120**A which also supports at least one heat source **130**. The heat source **130** is configured to direct radiant heat "H" toward the second side **112** of the support surface **110**A. Opposite the second side **112**, is the first side **111** of the support surface **110**A which is configured to movably support the product "P" thereon. As is seen, the configuration of the apparatus **100**A can provide for continuous processing of the product "P."

Turning now to FIG. **3**B, a side elevation diagram is shown which depicts an apparatus **100**B in accordance with a third embodiment of the present invention which is similar to the apparatus **100**A discussed above for FIG. **3**A. However, the support surface **110**B of the apparatus **100**B is not only configured as an endless belt, but also comprises a plurality of rigid links **113** which are pivotally connected to one another in a chain-like manner.

As shown, the apparatus **100**B comprises a chassis **120** which rotatably supports rollers **123** thereon. The rollers **123** in turn movably support the support surface **110**B thereon, which can be configured to move, or circulate, in the direction "D." The chassis **120** also supports a heat source **130** thereon which is configured to direct radiant heat "H" toward the second side **112** of the support surface **110**B. The support surface **110**B is configured to support the product "P" on the first side **111** which is opposite the second side **112**.

Moving to FIG. **3**C, a top plan view is shown of an apparatus **100**C in accordance with a fourth embodiment of the present invention. In accordance with the apparatus **100**C, the support surface **110**C is substantially configured as a flat, horizontal ring which is configured to rotate in the direction "R." The support surface **110**C can be configured to rotate in the direction "R" about a center portion **114** which can comprise a bearing (not shown) or the like. The upper, or first, side **111** of the support surface **110**A is configured to support the product "P" thereon.

The product "P" can be placed onto the first side **111** of the support surface **110**A at an application station **140**, and can be removed from the support surface at a removal station **142**. At least one heat source (not shown) can be positioned beneath the support surface **110**A such that radiant heat (not shown) is directed from the heat source to a lower, or second, side (not shown) which is opposite the first side **111**.

Returning now to FIG. **3**, the apparatus **100** can comprise a controller **150** such as a digital processor or the like for executing operational commands. The controller can be in communication with the radiant heat source **130** by way of the control device **131** as well as at least one communication link **151**. The communication link **151** can include either wire communication, or wireless communication means. The term "in communication with" means capable of sending or receiving data or commands in the form of signals which are passed via the communication link **151**.

The apparatus **100** can also comprise a sensor **160** which can be supported by a ceiling **102** or other suitable support, and which can be in communication with the controller **150** by way of a communication link **151**. The sensor **160** is configured to detect and measure at least one characteristic of at least a portion of the product "P." The characteristic can include, for example, the temperature of the product "P," the moisture content of the product, or the chemical composition of the product. The sensor **160** can be any of a number of sensor types which are known in the art. Preferably, the sensor **160** is either an infrared detector, or a bimetallic sensor.

The apparatus **100** can further include an operator interface **170** which is in communication with the controller **150** and which is configured to allow an operator to input commands or data into the controller **150** by way of a keypad or the like **172** which can be included in the operator interface. The operator interface **170** can also be configured to communicate information regarding the operation of the apparatus **100** to the operator by way of a display screen or the like **171** which can also be included in the operator interface. The controller can include an algorithm **153** which can be configured to automatically carry out various steps in the operation of the apparatus **100**. The controller **150** can further include a readable memory **155** such as a digital memory or the like for storing data.

During operation of the apparatus **100**, the product "P" can be placed upon the first side **111** of the support surface **110**. Various means of placing the product "P" upon the first side **111** can be employed, including spraying, dripping, pouring, and the like. The operator of the apparatus **100** can input various data and commands to the controller **150** by way of the operator interface **170**. These data and commands input by the operator can include the type of product "P" to be processed, the temperature profile to be maintained in the product, as well as "start" and "stop" commands.

The algorithm **153** can include at least one predetermined heat curve which is associated with at least one particular product "P." The term "heat curve" means a locus of values associated with the amount of heat produced by the heat source **130** and which locus of values is a function of elapsed time. After the operator identifies the particular product "P" and inputs this into the controller **150**, the drying process, in accordance with temperature parameters dictated by the predetermined heat profile, can be carried out automatically. In addition, the drying process can be adjusted "on the fly" based on inputs from the sensor **160** received by the controller during the process, as described below.

Once the drying operation begins, the sensor **160** can detect and measure at least one characteristic of at least a portion of the product "P" such as the temperature, moisture content, or chemical composition thereof. The sensor **160** can be instructed by the controller **150**, or otherwise configured, to repeatedly perform the detection and measurement of a characteristic of the product "P" at given intervals during the operation of the apparatus **100**. Alternatively, the sensor **160** can be configured to continuously detect and measure the characteristic during the operation of the apparatus **100**.

The measured characteristic which is detected and measured by the sensor **160** can be converted into a signal, such as a digital signal, and can then transmitted to the controller **150** by way of one of the communication links **151**. The controller **150** can then receive the signal sent by the sensor **160**, and can then store the signal as readable data in the readable memory **155**. The controller **150** can then cause the algorithm **153** to be activated, wherein the algorithm can access the data in the readable memory **155** and then use the data to initiate an automatic operational command.

For example, the controller **150** can use the signal data sent by the sensor **160** to control the radiant heat source **130**. That is, the controller **150** can use the signal data from the sensor **160** to control the amount of radiant energy "H" directed toward the support surface **110**. This can be accomplished in various manners such as by turning the heat source on or off for specific time intervals, or by proportionally modulating the heat output produced by the energy source **130**.

In a typical drying operation, for example, a product "P" can be placed onto the first side **111** of the support surface **110** as shown so as to be supported thereon. The operator can, by way of the interface **170**, communicate to the controller **150** the type of product "P" which is to be dried. Alternatively, the operator can enter other data such as the estimated moisture content, or the like, of the product "P." The operator can also cause the apparatus **100** to commence a drying operation by entering a "start" command into the interface **170**.

When the drying operation commences, the sensor **160** can detect and measure a characteristic of the product "P" such as the temperature, moisture content, or chemical composition thereof. The sensor **160** can then convert the measurement of the characteristic to a signal and then send the signal to the controller **150**. For example, if the measured characteristic is the temperature of the product, then the sensor can send to the controller **150** a signal which contains data regarding the temperature of the product.

The controller **150** can use the data sent by the sensor **160** to regulate various functions of the apparatus **100**. That is, the controller **150** can regulate the amount of radiant heat "H" produced by the radiant heat source **130** and directed to the product "P" as a function of the characteristic detected and measured by the sensor **160**.

The controller **150** can also regulate the amount of radiant heat "H" produced by the radiant heater **130** as a function of elapsed time, as well as the particular type of product "P" which is to be dried. In alternative embodiments such as those described above for FIGS. **3**A, **3**B, and **3**C, wherein the support surface **110** is configured to move the product "P" past the heat source **130**, the controller **150** can regulate the speed at which the support surface **110**, and thus the product, moves past the heat source.

The particular type of product "P" to be dried can have an optimum profile associated therewith, which, when adhered to, can optimize a given production result such as minimum drying time, or maximum quality of the product "P." The term "profile" means a locus of values of one or more measured product characteristics as a function of elapsed time. For example, a given product "P" can have associated therewith a given optimum temperature profile, an optimum moisture content profile, or an optimum chemical composition profile. The readable memory **155** can store optimum profiles for several types of products "P." Each of the stored optimum profiles can then be accessed by the algorithm **153** in accordance with instructions or commands entered into the controller **150** by the operator.

For example, the particular product "P" to be dried, for example, can have an optimum temperature profile that dictates an increase in the temperature of the product at a maximum rate possible and to a temperature of 100 degrees Centigrade. The optimum temperature profile can further dictate that, once the product "P" attains a temperature of 100 degrees Centigrade, the product temperature is to be maintained at 100 degrees Centigrade for an elapsed time of five minutes, after which the temperature of the product "P" is to decrease at a substantially constant rate to ambient temperature over an elapsed time of ten minutes.

The algorithm **153** can attempt to maintain the actual temperature of the product "P" so as to substantially match the optimum temperature profile stored in the a given temperature profile of the product "P" by regulating the amount of heat energy "H" produced by the heat source **130**. For example, in order to cause the temperature of the product "P" to increase rapidly so as to substantially match the optimum temperature profile, the algorithm **153** can cause the radiant heat source **130** to initially produce maximum output of radiant heat "H." This can be accomplished by causing the temperature of the heat source to increase rapidly to a relatively high level.

The heat energy "H" is directed from the heat source **130** to the second side **112** of the support surface **110**. Because the support surface **110** in configured to allow the radiant heat "H" to pass there through, the product "P" will absorb at least a portion of the radiant heat. The absorption of the heat energy "H" by the product "P" results in an increased temperature of the product which, in turn, promotes moisture evaporation from the product. When the sensor **160** detects that the product "P" has reached a given temperature, such as 100 degrees Centigrade, the algorithm **153** can then begin a first elapsed time countdown having a given duration, such as five minutes.

During the first countdown, the algorithm **153**, in conjunction with temperature measurements received from the sensor **160**, can regulate the amount of heat output "H" produced by the radiant heat source **130** in order to maintain the temperature of the product "P" at a given temperature, such as 100 degrees Centigrade. For example, as moisture evaporates from the product "P," the product can require less heat energy "H" to maintain a given temperature. At the end of the first countdown, the algorithm **153** can then begin a second elapsed time countdown having a given duration, such as ten minutes.

During the second countdown, the algorithm **153** can control the heat output "H" of the radiant heat source **130** in accordance with the temperature measurements received from the sensor **160** in order to maintain an even decrease in the product temperature from, for example, 100 degrees Centigrade to ambient temperature, whereupon the drying operation is complete. Once the product "P," attains ambient temperature, or another given temperature, controller **150** can send a signal to the operator interface **170** which, in turn, can generate an audible or visual signal detectable by the operator. This audible or visual signal can alert the operator that the drying operation is complete. The operator can then remove the finished, dried product "P" from the apparatus **100**.

Moving now to FIG. 3D, a side elevation diagram is shown of an apparatus **100**D which is an alternate configuration in accordance with a fifth embodiment. The apparatus **100**D depicts an alternative control scheme which can be used in place of that depicted in FIG. **3** for the apparatus **100**. In accordance with the alternative control scheme which is depicted in FIG. **3**D, the apparatus **100**D can comprise a display **177** and a manual heat source control **178**. The display **177** is connected to the sensor **160** by way of a communication link **151**. The display is configured to display data relating to at least on characteristic of the product "P" which is detected and measured by the sensor **160**.

The manual heat source control **178** is connected to the relay **131** by way of another lo communication link **151**. The manual heat source control **178** is configured to receive operator input commands relating to the amount of heat "H" produced by the heat source **130**. That is, the manual heat source control **178** can be set by the operator to cause the heat source **130** to produce a given amount of heat "H."

In operation, the operator can initially set the manual heat source control **178** to cause the heat source **130** to produce a given amount of heat "H." The manual heat source control **178** then sends a signal to the relay **131** by way of a communication link **151**. The relay **131** then receives the signal and causes the heat source **130** to produce the given amount of heat "H." The operator then monitors the display **177**.

The sensor **160** can continually detect and measure a given characteristic of the product "P." The sensor can send a signal to the display **177** which relates to the measured characteristic. The display receives the signal and converts the signal to a value which it displays and which is readable by the operator. The operator can then adjust the heat "H" produced by the heat source **130** in response to the information relating to the measured characteristic which is read from the display **177**.

As is seen, the apparatus **100**, as well as the various other configurations thereof and related embodiments, can allow for much greater control of the amount of heat that is transferred to the product than can the various apparatus of the prior art. Because of this, the apparatus **100** of the present invention can produce products "P" having higher quality, and can produce the products in a more efficient manner, than the drying apparatus of the prior art.

As is further seen, the apparatus **100** can be suited for "batch" type of drying processes in which case the support surface **110** is not necessarily moved during the drying operation. In alternative embodiments such as those depicted in FIGS. **3**A, **3**B, and **3**C, the support surface **110** can be configured to move the product "P" past the radiant heat source **130** and sensor **160**, in which case a continuous drying process can be attained. In yet another embodiment of the present invention, which is described below, an apparatus **200** can be particularly suitable for producing a high-quality product in a high-output, continuous drying process.

Drying Apparatus with Multiple Control Zones

Referring to FIG. **4**, a side elevation view of a drying apparatus **200** in accordance with a sixth embodiment is depicted. The apparatus **200** comprises a chassis **210** which can be a rigid structure comprising various structural members including legs **212** and longitudinal frame rails **214** connected thereto. The legs **212** are configured to support the apparatus **200** on a floor **201** or other suitable base.

The chassis **210** can also comprise various other structural members, such as cross-braces (not shown) and the like. The chassis **210** can be generally constructed in accordance with known construction methods, including welding, fastening, forming and the like, and can be constructed from known materials such as aluminum, steel and the like. The apparatus **200** is generally elongated and has a first, intake end **216**, and an opposite, distal, second, out feed end **218**.

The apparatus **200** can further comprise a plurality of substantially parallel, transverse idler rollers **220** which are mounted on the chassis **210** and configured to rotate freely with respect thereto. At least one drive roller **222** can also be included in the apparatus **200** and can be supported on the chassis **210** in a substantially transverse manner as shown.

An actuator **240**, such as an electric motor, can be included in the apparatus **200** as well, and can be supported on the chassis **210** proximate the drive roller **222**. A drive linkage **240** can be employed to transfer power from the actuator **240** to the drive roller **222**. A speed controller **244**, such as an alternating current ("A/C") variable speed control device or the like, can be included to control the output speed of the actuator **240**.

The apparatus **200** comprises a support surface **230**, which has a first side **231** and an opposite second side **232**. The support surface **230** is movably supported on the chassis **210**. The support surface **230** is configured to allow radiant heat energy to pass there through from the second side **212** to the first side **211**.

Preferably, the support surface **230** is fabricated from a material comprising plastic. More preferably, the support surface **230** is fabricated from a material selected from the group consisting of acrylic and polyester. Also, preferably, the support surface **230** is configured to withstand temperatures of up to at least 300 degrees Fahrenheit. The support surface **230** is configured as an endless flexible belt as shown, at least a portion of which can preferably be substantially flat and level.

As an endless belt form, the support surface **230** is preferably supported on the idler rollers **220** and drive roller **222**. The support surface **230** can be configured to be driven by the drive roller **222** so as to move, or circulate, in the direction "D" relative to the chassis **210**. As is seen, the support surface **230** can be configured so as to extend substantially from the intake end **216** to the out feed end **218**. A take up device **224** can be supported on the chassis **210** and employed to maintain a given tension on the support surface **230**.

The first side **231** of the support surface **230** is configured to support a layer of product "P" thereon as shown. The first side **231** is further configured to move the product "P" substantially from the intake end **216** to the out feed end **218**. The product "P" can be in one of many possible forms, including liquid colloidal suspensions, solutions, syrups, and pastes. Is the case of a liquid product "P" having a relatively low viscosity, an alternative embodiment of the apparatus which is not shown can include a longitudinal, substantially upwardly-extending lip (similar to the lip **115** shown in FIG. **3**) which can be formed on each edge of the support surface **230** to prevent the product from running off.

The product "P" can be applied to the first side **231** of the support surface **230** by an application device **252** which can be included in the apparatus **200** and which can be located proximate the intake end **216** of the apparatus **200**. In the case of a liquid product "P," the product can be applied to the support surface **230** by spraying, as shown. Although FIG. **4** depicts a spraying method of applying the product "P" to the support surface **230**, it is understood that other methods are equally practicable, such as dripping, brushing, and the like.

A removal device **254** can also be included in the apparatus **200**. The removal device **254** is located proximate the out feed end **218**, and is configured to remove the product "P" from the support surface **230**. The product "P" can be in a dry or semi-dry state when removed from the support surface **230** by the removal device **254**.

The removal device **254** can comprise a sharp bend in the support surface **230** as shown. That is, as depicted, the removal device **254** can be configured to cause the support surface **230** to turn sharply around a corner having a radius which is not more than about twenty times the thickness of the support surface **230**. Also, preferably, the support surface **230** forms a turn at the removal device **254** which turn is greater than 90 degrees. More preferably, the turn is about between 90 degrees and 175 degrees.

The type of removal device **254** which is depicted can be particularly effective in removing certain types of product "P" which are substantially dry and which exhibit substantially self-adherence properties. It is understood, however, that other configurations of removal devices **254**, which are not shown, can be equally effective in removing various forms of product "P" from the support surface, including scraper blades, low frequency vibrators, and the like. As the product "P" is removed from the support surface **230** at the out feed end **218**, a collection hopper **256** can be employed to collect the dried product. Depending on the application, the dried product can be subjected to further processing, such as milling, grinding or otherwise processing the dried product into a powder.

The apparatus **200** comprises a heater bank **260** which is supported on the chassis **210**. The heater bank **260** comprises one or more first heat sources **261** and one or more second heat sources **262**. The heater bank **260** can also comprise one or more third heat sources **263** and at least one pre-heater heat source **269**. The heat sources **261**, **262**, **263**, **269** are supported on the chassis **210** and are configured to direct radiant heat "H" across a gap "G" and toward the second side **232** of the support surface **230**.

Each of the heat sources **261**, **262**, **263**, **269** are dry radiant heat sources as defined above for FIG. **3**. The heat sources **261**, **262**, **263**, **269** are preferably selected from the group consisting of gas radiant heaters and electric radiant heaters. Furthermore, each of the heat sources **261**, **262**, **263**, **269** is preferably configured to modulate, or incrementally vary, the amount of radiant heat produced thereby in a proportional manner. The operation of the heat sources **261**, **262**, **263**, **269** is more fully described below.

The apparatus **200** can comprise an enclosure **246**, such as a hood or the like, which is employed to cover the apparatus. The enclosure **246** can be configured to contain conditioned air "A" which can be introduced into the enclosure through an inlet duct **226**. Before entering the enclosure, the conditioned air "A" can be processed in air conditioning unit (not shown) so as to have a temperature and humidity which is beneficial to drying of the product "P." The conditioned air "A" can circulate through the enclosure **246** before exiting the enclosure by way of an outlet duct **228**. Upon exiting the enclosure **246**, the conditioned air "A" can be returned to the air conditioning unit, or can be vented to exhaust.

The apparatus **200** can further comprise a first sensor **281**, a second sensor **282**, and a third sensor **283**. It is understood that, although three sensors **281**, **282**, **283** are depicted, any number of sensors can be included in the apparatus **200**. Each of the sensors **281**, **282**, **283** can be supported on the enclosure **246**, or other suitable structure, in a substantially evenly spaced manner as shown. Each of the sensors **281**, **282**, **283** can be any of a number of sensor types which are known in the art. Preferably, in the case of detecting temperature of the product "P," each of the sensors **281**, **282**, **283** is either an infrared detector or a bimetallic sensor.

Preferably, the sensors **281**, **282**, **283** are positioned so as to be substantially exposed to the first side **231** of the support surface **230**. The sensors **281**, **282**, **283** are configured to detect and measure at least one characteristic of the product "P" while the product is movably supported on the first side **231** of the support surface **230**. Characteristics of the product "P" which are detectable and measurable by the sensors **281**, **282**, **283** can include the temperature, moisture content, and chemical composition of the product. Operational aspects of the sensors **281**, **282**, **283** are more fully described below.

The apparatus **200** can comprise a controller **250** for controlling various functions of the apparatus during operation thereof. The controller **250** can include any of a number of devices such as a processor (not shown), a readable memory (not shown), and an algorithm (not shown). The controller **250** will be discussed in further detail below. In addition to the controller **250**, the apparatus **200** can include an operator interface **235** which can be in communication with the controller.

The operator interface **235** can be configured to relay information regarding the operation of the apparatus **200** to the operator by way of a display screen **237** such as a CRT or the like. Conversely, the operator interface **235** can also be configured to relay data or operational commands from the operator to the controller **250**. This can be accomplished by way of a keypad **239** or the like which can also be in communication with the controller **250**.

As is seen, a plurality of control zones Z**1**, Z**2**, Z**3** are defined on the apparatus **200**. That is, the apparatus **200** includes at least a first control zone Z**1**, which is defined on the apparatus between the intake end **216** and the out feed end **218**. A second control zone Z**2** is defined on the apparatus **200** between the first control zone Z**1** and the out feed end **218**. The apparatus **200** can include additional control zones as well, such as a third control zone Z**3** which is defined on the apparatus between the second control zone Z**2** and the out feed end. Each control zone Z**1**, Z**2**, Z**3** is defined to be stationary relative to the chassis **210**.

A study of FIG. **4** will reveal that each first heat source **261**, as well as the first sensor **281** are located within the first control zone Z**1**. Likewise, each second heat source **262**, and the second sensor **282**, are located within the second control zone Z**2**. Each third heat source **263**, and the third sensor **283**, are located within the third control zone Z**3**. It is further evident that the support surface **230** moves the product "P" through each of the control zones Z**1**, Z**2**, Z**3**. That is, as the actuator **240** moves the support surface **230** in the direction "D," a given portion of the product "P" which is supported on the support surface, is moved successively through the first control zone Z**1** and then through the second control zone Z**2**.

After being moved through the second control zone Z**2**, the given portion of the product "P" can then be moved through the third control zone Z**3** and on to the removal device **254**. As is seen, at least a portion of the heater bank **260**, such as the pre-heater heat source **269**, can lie outside any of the control zones Z**1**, Z**2**, Z**3**. Furthermore, a cooling zone **248** can be defined relative to the chassis **210** and proximate the out feed end **218** of the apparatus **200**. The cooling zone **248** can be configured to employ any of a number of known means of cooling the product "P" as the product passes through the cooling zone.

For example, the cooling zone **248** can be configured to employ a refrigerated heat sink (not shown) such as a cold black body, or the like, which is exposed to the second side **232** of the support surface **230** and which positioned within the cooling zone. Such a heat sink can be configured to cool the product "P" by radiant heat transfer from the product and through the support surface **230** to the heat sink. One type of heat sink which can be so employed can be configured to comprise an evaporator coil which is a portion of a refrigeration system utilizing a fluid refrigerant such as Freon or the like.

It is understood that the cooling zone **248** can have a relative length which is different than depicted. It is further understood that other means of cooling can be employed. For example, the cooling zone **248** can be configured to incorporate a convection cooling system (not shown) in which cooled air is directed at the second side **232** of the support surface **230**. Furthermore, the cooling zone **248** can be configured to incorporate a conductive cooling system (not shown) in which refrigerated rollers or the like contact the second side **232** of the support surface **230**. The operation of the apparatus **200** can be similar to that of the apparatus **100** in accordance with the first embodiment of the present invention which is described above for FIG. **3**, except that the product "P" is moved continuously past the heat sources **261**, **262**, **263**, **269** and sensors **281**, **282**, **283**. As depicted in FIG. **4**, the product "P" can be applied to the first side **231** of the moving support surface **230** proximate the intake end **216**.

The support surface **230** is driven by the actuator **240** by way of the drive link **242** and drive roller **222** so as to revolve in the direction "D" about the idler rollers **220**. The product "P" can be in a substantially liquid state when applied to the support surface **230** by the application device **252**. The product "P," which is to be dried by the apparatus **200**, is fed there through in the feed direction "F" toward the out feed end **218**.

The product "P," while supported on the support surface **230** and moved through the apparatus **200** in the direction "F," passes the heater bank **260** which can be positioned in substantially juxtaposed relation to the second side **232** of the support surface so as to be exposed thereto as shown. The heater bank **260** comprises one or more first heat sources **261** and one or more second heat sources **262** which are configured to direct radiant heat "H" toward the second side **232** and through the support surface **230** to heat the product "P" which is moved in the direction "F."

The heater bank **260** can also comprise one or more third heat sources **263** and one or more pre-heater heat sources **269** which are also configured to direct radiant heat "H" toward the second side **232** to heat the product "P." The product "P," while moving on the support surface **230** in the feed direction "F," is dried by the radiant heat "H" to a desired moisture content, and then removed from the support surface at the out feed end **218** by the removal device **254**.

The product "P," once removed from the support surface **230**, can be collected in a collection hopper **256** or the like for storage, packaging, or further processing. The support surface **230**, once the product "P" is removed there from, returns to the intake end **216** whereupon additional product can be applied by the application device **252**.

In order to promote efficient product drying as well as high product quality, conditioned air "A" can be provided by an air conditioning unit (HVAC) **245**, and can be circulated about the product "P" by way of the enclosure **246**, intake duct **226**, and outlet duct **228** as the product is moved through the apparatus **200** in the feed direction "F" concurrent with the direction of the movement of the product.

As a further enhancement to production rate and product quality, a plurality of control zones can be employed. The term "control zone" means a stationary region defined on the apparatus **200** through which the product "P" is moved and in which region radiant heat is substantially exclusively directed at the product by one or more dedicated heat sources which are regulated independently of heat sources outside of the region. That is, a given control zone includes a dedicated servomechanism for controlling the amount of heat directed at the product "P" which is within the given control zone, wherein the amount of heat is a function of a measured characteristic of the product.

As is seen, the support surface **230** is configured to move the product "P" in succession through a first control zone Z**1**, and then through a second control zone Z**2**. This can be followed by a third control zone Z**3**. Within the first control zone Z**1**, one or more first heat sources **261** direct radiant heat "H" across the gap "G" toward the product "P" as the product moves through the first control zone. Likewise, within the second control zone Z**2** and within the third control zone Z**3**, one or more second heat sources **262** and one or more third heat sources **263**, respectively, direct radiant heat "H" across the gap "G" toward the product "P" as the product moves through the second and third control zones, respectively.

The temperature of, and thus the amount of heat "H" produced by, the first radiant heat sources **261** is regulated independently of the temperature of, and amount of heat produced by, the second heat sources **262**. Similarly, the third heat sources **263** are regulated independently of the first and second heat sources **261**, **262**. The use of the control zones Z**1**, Z**2**, Z**3** can provide for greater control of production parameters as compared to prior art devices.

That is, specific product profiles and heat curves can be attained with the use of the apparatus **200** because the product "P" can be exposed to different amounts of heat "H" in each control zone Z**1**, Z**2**, Z**3**. Specifically, for example, the first heat sources **261** can be configured to produce heat "H" at a first temperature. The second heat sources **262** can be configured to produce heat "H" at a second temperature which is different from the first temperature. Likewise, the third heat sources **263** can be configured to produce heat "H" at a third temperature.

Thus, as the product "P" proceeds through the apparatus in the feed direction "F," the product can be exposed to a different amount of heat "H" in each of the control zones Z**1**, Z**2**, Z**3**. This can be particularly useful, for example, in decreasing the drying time of the product "P" as compared to drying times in prior art apparatus. This can be accomplished by rapidly attaining a given temperature of the product "P" and then maintaining the given temperature as the product proceeds in succession through the control zones Z**1**, Z**2**, Z**3**. The use of the control zones Z**1**, Z**2**, Z**3** can also be useful in providing tight control of the amount of heat "H" which is transmitted to the product "P" so as to provide greater product quality. That is, product quality can be enhanced by utilizing the control zones Z**1**, Z**2**, Z**3** to minimize over-exposure and under-exposure of the product "P" to heat energy "H."

Assuming a given product "P" is relatively moist and at ambient temperature when placed onto the support surface **230** by the application device **252**, a relatively large amount of heat "H" is required to raise the temperature of the product to a given temperature such as 100 degrees Centigrade. Thus, a pre-heater heat source **269** can be employed to pre-heat the product "P" before the product enters the first control zone Z**1**. The pre-heater heat source **269** can be configured to continually produce radiant heat "H" at a maximum temperature and to direct a maximum amount of heat "H" to the product "P."

As the product "P" enters the first control zone Z**1**, the first heat sources **261** within the first control zone Z**1** can be configured to produce an amount of heat "H" which sufficient to attain the given desired product temperature. The first sensor **281**, in conjunction with the controller **250**, can be employed to regulate the temperature of the first heat sources **261** in order to transfer the desired amount of heat "H" to the product "P." The first sensor **281** is configured to detect and measure at least one given characteristic of the product "P" while the product is within the first control zone Z**1**. For example, the first sensor **281** can be configured to detect and measure the temperature of the product "P" while the product is within the first control zone Z**1**.

The first sensor **281** can detect and measure a characteristic of the product "P" while the product is in the first control zone Z**1** and then relay that measured characteristic to the controller **250**. The controller **250** can then use the measurement from the first sensor **281** to modulate the temperature, or heat output, of the first heat sources **261**. That is, the heat "H" produced by the first heat sources **261** can be regulated as a function of a measured product characteristic of the product "P" within the first control zone Z**1** as detected and measured by the first sensor **281**. This measured product characteristic can include, for example, the temperature of the product.

The second sensor **282** is similarly employed to detect and measure at least one characteristic of the product "P" while the product is within the second control zone Z**2**. Likewise, the third sensor **283** can be employed to detect and measure at least one characteristic of the product "P" while the product is within the third control zone Z**3**.

The product characteristics detected and measured by the second and third sensors **282**, **283** within the second and third control zones Z**2**, Z**3**, respectively, can be likewise utilized to modulate the amount of heat "H" produced by the second and the third heat sources **262**, **263** to maintain a specific temperature profile of the product "P" as the product progresses through each of the control zones.

In the case wherein the product "P" is heated rapidly to a given temperature and then maintained at the given temperature, the first heat sources **261** will likely produce heat "H" at a relatively high temperature in order to rapidly increase the product temperature to the given temperature by the time the product "P" leaves the first zone Z**1**. Assuming that the product "P" is at the given temperature when entering the second control zone Z**2**, the second and third heat sources **262**, **263** will produce heat "H" at a successively lower temperatures because less heat "H" is required to maintain the temperature of the product as the moisture content thereof decreases.

As mentioned above, the sensors **281**, **282**, **283** can be configured to detect and measure any of a number of product characteristics, such as moisture content. This can be particularly beneficial to the production of a high-quality product "P." For example, in the above case wherein the product temperature has reached the given temperature as the product "P" enters the second control zone Z**2**, the second and third sensors **282**, **283** can detect and measure product moisture content as the product progresses through the respective second and third control zones Z**2**, Z**3**.

If the second sensor **282** detects and measures a relatively high product moisture content of the product "P" within the second control zone Z**2**, then the controller **250** can modulate the second heat sources **262** so as to continue to maintain the product temperature at the given temperature in order to continue drying of the product. However, if the second sensor **282** detects a relatively low product moisture content, then the controller **250** can modulate the second heat sources **262** so as to reduce the product temperature in order to prevent over-drying the product "P."

Likewise, the third sensor **283** can detect and measure product moisture content within the third control zone Z**3**, whereupon the controller can determine the proper amount of heat "H" to be produced by the third heat sources **263**. Although three control zones Z**1**, Z**2**, Z**3** are depicted, it is understood that any number of control zones can be incorporated in accordance with the present invention.

In furtherance of the description of the interaction between the controller **250**, the sensors **281**, **282**, **283**, and the heat sources **261**, **262**, **263** provided by the above example, a given control zone Z**1**, Z**2**, Z**3** can be described as a separate, independent, and exclusive control loop which comprises each associated sensor and each associated heat source located within the given control zone, and which is, along with the controller, configured to independently regulate the amount of heat "H" produced by the associated heat sources as a function of at least one characteristic of the product "P" measured by the associated sensor.

That is, each sensor **281**, **282**, **283** associated with a given control zone Z**1**, Z**2**, Z**3**, can be considered as configured to provide control feedback to the controller **250** exclusively with regard to characteristics of a portion of the product "P" which is in the given control zone. The controller **250** can use the feedback to adjust the output of the heat sources **261**, **262**, **263** in accordance with a temperature profile or other such parameters defined by the operator or otherwise stored within the controller.

In addition to decreasing the drying time of the product "P" as compared to prior art drying apparatus, the plurality of control zones Z**1**, Z**2**, Z**3** of the apparatus **200** can also be employed to attain specific product profiles which can be beneficial to the quality of the product as described above for the apparatus **100**.

For example, it can be assumed that the quality of a given product "P" can be maximized by following a given product temperature profile during drying. The given product temperature profile can dictate that, as the product "P" passes successively through the first, second, and third control zones Z**1**, Z**2**, Z**3**, the temperature of the product initially increases rapidly to a maximum given temperature, whereupon the temperature of the product "P" gradually decreases until it is removed from the support surface **230**.

In that case, the first sensor **281**, first heat sources **261** and controller **250** can operate in a manner similar to that described above in order to rapidly increase the product "P" temperature to a first temperature which can be reached as the product "P" passes through the first control zone Z**1**. The first temperature can correspond to a relatively large amount of heat "H" which is transferred to the product "P" which initially contains a high percentage of moisture.

As the product "P" passes through the second control zone Z**2**, the second sensor **282**, second heat sources **262** and controller **250** can operate to decrease the product temperature to a relatively medium second temperature which is lower than the first temperature. The second temperature can correspond to a lesser amount of heat "H" which is required as the moisture content of the product "P" drops.

Likewise, as the product "P" passes through the third control zone Z**3**, the third sensor **283**, third heat sources **263** and controller **250** can operate to decrease the product temperature further to a relatively low third temperature which is lower than the second temperature. The third temperature can correspond to a relatively low amount of heat "H" which is required as the product "P" approaches the desired dryness.

In addition to regulating the temperature of the heat sources **261**,**262**,**263**, the controller **250** can also be configured to regulate the speed of the support surface **230** relative to the chassis **210**. This can be accomplished by configuring the controller **250** so as to modulate the speed of the actuator **240**. For example, as in the case where the actuator **240** is an A/C electric motor, the controller can be configured so as to modulate the variable speed control unit **244** by way of a servo or the like.

The speed, or rate of movement, of the support surface **230** can affect the process of drying the product "P" which is performed by the apparatus **200**. For example, a relatively slow speed of the support surface **230** can increase the amount of heat "H" which is absorbed by the product "P" because the slower speed will cause the product to be exposed to the heat "H" for a longer period of time. Conversely, a relatively fast speed of the support surface **230** can decrease the amount of heat "H" which is absorbed by the product "P" because the faster speed will result in less exposure time during which the product is exposed to the heat.

Moreover, the controller **250** can also be configured to regulate various qualities of the conditioned air "A" which can be made to circulate through the enclosure **246**. For example, the controller **250** can be made to regulate the flow rate, relative humidity, and temperature of the conditioned air "A." These qualities of the conditioned air "A" can have an effect on both the drying time and quality of the product "P."

In another alternative embodiment of the apparatus **200** which is not shown, the enclosure **246** can be configured so as to be substantially sealed against outside atmospheric air. In that case, the chemical composition of the conditioned air "A" can be controlled so as to affect the drying process in specific manners, or to affect or preserve the chemical properties of the product "P." For example, the conditioned air "A" can substantially be inert gas which can act to prevent oxidation of the product "P."

Moving to FIG. **5**, a schematic diagram is shown which depicts one possible configuration of the apparatus **200** which comprises a plurality of communication links **257**. The communication links **257** are configured to provide for the transmission of data signals between the various components of the apparatus **200**. The communication links **257** can be configured as any of a number of possible communication means, including those of hard wire and fiber optic. In addition, the communication links **257** can comprise wireless communication means including infrared wave, micro wave, sound wave, radio wave and the like.

A readable memory storage device **255**, such as a digital memory, can be included within the controller **250**. The readable memory device **255** can be employed to store data regarding the operational aspects of the apparatus **200** which are received by the controller by way of the communication links **257**, as well as set points and other stored values and data which can be used by the controller **250** to control the drying process. The controller **250** can also include at least one algorithm **253** which can be employed to carry out various decision-making processes required during operation of the apparatus **200**.

The decision-making processes taken into account by the algorithm **253** can include maintaining integrated coordination of the several variable control aspects of the apparatus **200**. These variable control aspects comprise the speed of the support surface **230**, the amount of heat "H" produced by each of the heat sources **261**, **262**, **263**, **269**, and the product characteristic measurements received from the sensors **281**, **282**, **283**. Additionally, the algorithm **253** can be required to carry out the operational decision-making processes in accordance with various set production parameters such as a product temperature profile and production rate.

The communication links **257** can provide data transmission between the controller **250** and the operator interface **235** which can comprise a display screen **237** and a keypad **239**. That is, the communication links **257** between the controller **250** and operator interface **235** can provide for the communication of data from the controller to the operator by way of the display screen. Such data can include various aspects of the apparatus **200** including the temperature and moisture content of the product "P" with regard to the position of the product within each of the control zones Z**1**, Z**2**, Z**3**.

Additionally, such data can include the speed of the support surface with respect to the chassis **210** and the temperature of each of the heat sources **261**, **262**, **263**, **269**. The communication links **257** can also provide for data to be communicated from the operator to the controller **250** by way of the keypad **239** or the like. Such data can include operational commands including the specification by the operator of a given product temperature profile.

A communication link **257** can be provided between the controller **250** and the HVAC unit **245** so as to communicate data there between. Such data can include commands from the controller **250** to the HVAC unit **245** which specify a given temperature, humidity, or the like, of the conditioned air "A." A communication link **257** can also be provided between the controller **250** and the actuator **240** so as to communicate data there between. This data can include commands from the controller **250** to the actuator which specify a given speed of the support surface **230**.

Additional communication links **257** can be provided between the controller **250** and each of the sensors **281**, **282**, **283** so as to communicate data between each of the sensors and the controller. Such data can include measurements of various characteristics of the product "P" as described above for FIG. **4**. Other communication links **257** can be provided between the controller **250** and each of the heat sources **261**, **262**, **263**, **269** so as to provide transmission of data there between.

This data can include commands from the controller **250** to each of the heat sources **261**, **262**, **263**, **269** which instruct each of the heat sources as to the amount of heat "H" to produce. As can be seen, the apparatus **200** can include a plurality of control devices **233**, which can comprise electrical relays, wherein each one of the control devices is connected by way of respective communication links **257** to the controller **250**. Each of the control devices can be configured in the manner of the control device **131** which is described above for FIG. **3**.

In accordance with a seventh embodiment of the present invention, a method of drying a product includes providing a support surface which has a first side, and an opposite second side, and supporting the product on the first side while directing radiant heat toward product. Preferably, the support surface can allow radiant heat to pass there through so as to heat the product. The support surface can be a substantially flexible sheet. Alternatively, the support surface can be substantially rigid.

The method can further include the step of measuring a characteristic of the product, along with regulating the amount of radiant heat directed toward the second side as a function of the measured characteristic. The measured characteristic can include the temperature of the product, the moisture content of the product, and the chemical composition of the product. The characteristic can be detected and measured intermittently at given intervals, or it can be measured continually over a given time interval.

The method can also include moving the support surface so as to move the product past the heat source. Alternatively, the method can include moving the support surface so as to move the product through a plurality of control zones in succession, and providing a plurality of heat sources, wherein each control zone has at least one associated heat source dedicated exclusively to directing radiant heat within the associated control zone.

In other words, the method can include regulating the temperature of the heat sources within any given control zone independently of the temperature of any other heat sources outside the given control zone. This can allow producing and maintaining a given temperature profile of the product as the product is moved through the control zones.

The method can further include providing a plurality of sensors, wherein any given control zone has at least one sensor dedicated exclusively to detecting and measuring at least one characteristic of the product within the given control zone. This can allow regulating the temperature of each heat source in any given control zone as a function of at least one characteristic of the product within the given control zone. As noted above, the characteristics can include the temperature, moisture content, and chemical composition of the product, among others.

The rate of movement of the support surface relative to the control zones can also be regulated in accordance with the method. Additionally, an enclosure can be provided to aid in circulating conditioned air about the product as the product is processed by the apparatus. The quality of the conditioned air can be controlled, wherein such qualities can include the temperature, humidity, and chemical makeup of the conditioned air. The method can include annealing the product which the product is supported on the support surface.

Drying Apparatus with Movable Heaters

Another aspect of the present disclosure concerns a drying apparatus that is capable of independently controlling the temperature of the product being heated (e.g., to achieve a desired temperature profile) and the wavelength of the radiation (e.g., to maximize the heat transfer rate). To such ends, a drying apparatus can be provided with one or more heat sources that are movable relative to the product "P" in order to increase or decrease the gap or spacing between the heat source and the product "P". By adjusting the gap between the product and the heat source, it is possible to control the source temperature in such a manner that produces the desired product temperature and wavelength of radiation. For example, as noted above, if a particular drying profile requires that the temperature of the product remain substantially constant through one or more control zones, then the product typically is subjected to less heat in each successive control zone. To maintain the desired product temperature and wavelength of radiation, the heaters in a control zone can be moved farther away from the product to decrease the heat applied to the product while maintaining the source temperature to produce radiation at the desired wavelength. For example, if desired, the source temperature and heater positions can be controlled to produce a predetermined constant wavelength in successive zones to compensate for changes in energy required to evaporate moisture as the moisture content in the product decreases as it is dried through each of the zones.

Alternatively, if desired, the source temperature can be adjusted to produce a desired wavelength in a control zone that is different than the wavelength in the preceding control zone and the gap between the heat source and the product can be adjusted accordingly to achieve the desired product temperature. This allows the dryer to compensate for other product characteristics that can vary in each zone or from zone to zone during the drying process, such as the emissivity of the product, the thickness of the product, changes in sensitivity of the product (or specific compounds in the product) to a particular wavelength of IR (infrared radiation), and the ability to release bound moisture in the product (the ability to release bound moisture decreases as the product is dried). The controller of the dryer can be configured to continuously monitor the wavelength of the heat sources and the temperature of the product during the drying process, and automatically adjust the temperature and the positions of the heat sources to maintain the desired product temperature and wavelength within each heating zone.

Referring now to FIG. **6**, there is shown a drying apparatus **200**A, according to an eighth embodiment of the present disclosure. The drying apparatus **200**A is a modification of the drying apparatus **200** of FIGS. **4** and **5**. One difference between the drying apparatus **200**A and the drying apparatus **200** is that the drying apparatus **200**A has heat sources that are movable upwardly and downwardly relative to the product "P". The drying apparatus **200**A includes a chassis **300** that is modified relative to the chassis **210** of FIG. **4** in that it includes movable platforms, or heater supports, **302**, **304**, **306**, **308** that support heat sources **269**, **261**, **262**, **263**, respectively. The heat sources **269**, **261**, **262**, **263** can comprise heating elements that produce radiant heat in the infrared spectrum. Each platform **302**, **304**, **306**, **308** is mounted on a pair of upright legs **310** of the chassis **300** and is configured to move upwardly and downwardly relative thereto, as indicated by double-headed arrows **312**.

In particular embodiment, each heater support supports a set of one or more quartz heating elements for producing infrared radiation. Each such heating element can comprise a coiled wire encased in quartz tubing. The quartz tubing can be frosted, as known in the art, to increase the heat capacitance of the heating element. The quartz tubing can include additives, such as silicon or graphite, to further increase the heat capacitance of the heating element. Increased heat capacitance can provide better control of the operating temperature of the heating element, such as if an "on/off" type switch or relay is used to modulate current to the heating elements.

As shown in FIG. **6**, each heat source within a control zone Z**1**, Z**2**, or Z**3** is supported on a common platform, and therefore each heat source within a specific control zone moves upwardly and downwardly together. In alternative embodiments, less than three heat sources can be mounted on a single platform. For example, each heat source can be mounted on a separate platform and its vertical position can be adjusted relative to other heat sources within the same control zone. In still other embodiments, a single platform can extend into multiple zones to support heat sources in adjacent control zones.

Mounted within each heating zone (control zones Z**1**, Z**2**, Z**3** and pre-heat zone PH) directly above a heat source are one or more temperature-sensing devices to measure the temperature of the heat sources, such as one or more thermocouples **314**. Each thermocouple **314** is positioned to monitor the surface temperature of the heating elements of a corresponding heat source and is in communication with the controller **250** (FIG. **5**). As described in greater detail below, a feedback control loop is provided to continuously monitor the temperature of the heat sources within each heating zone and adjust the vertical position of the heat sources and/or the temperature of the heat sources to achieve a predetermined wavelength and a predetermined product temperature using radiant energy. In the illustrated embodiment, one thermocouple is located within each heating zone. However, in other embodiments, more than one thermocouple can be used in each heating zone. For example, if each heat source is mounted on its own platform, then it would be desirable to position at least one thermocouple above each heat source. A thermocouple **314** can be mounted at any convenient position adjacent the heating elements of a corresponding heat source. For example, a thermocouple can be mounted to the support frame or pan of a heat source that supports one or more heating elements.

In lieu of or in addition to thermocouples, the dryer can include in each heating zone one or more sensors, such as an infrared spectrometer or radiometer, for measuring the energy or the wavelength of infrared energy that reaches the product. Such sensors can be mounted at any convenient locations on the dryer, such as directly above the support surface **230** and the product, preferably directly above an edge portion of the support surface that is not covered by the layer of product. This method has the advantage of allowing the system to compensate for changes in the actual IR wavelength reaching the product that can vary due to the transparency and refractive properties of the support surface **230**, as well as IR energy that is emitted from the heater pan surfaces or from reflectors in the heater pans. The wavelength or energy sensors can replace the heater thermocouples **314** (or can be used in combination with the thermocouples) as a means to determine the wavelength of radiant energy emitted from the heat sources in a control scheme whereby the vertical positions of the heat sources and/or their temperatures are adjusted to achieve a predetermined wavelength and a predetermined product temperature within each zone.

Any suitable techniques or mechanisms can be used to effect vertical movement of each platform **302**, **304**, **306**, **308** relative to support legs **310**. FIG. **7**, for example, is a schematic illustration of control zone Z**1** showing platform **304** having drive gears **316** mounted on opposite sides of the platform. Each drive gear **316** engages a respective rack gear **318** mounted on a respective support leg **310** of the chassis. The drive gears **316** can be powered by an electric motor **320** mounted at a convenient location on the platform. The motor **320** can be operatively coupled to each drive gear **316** by a drive shaft (not shown) such that operation of the motor is effective to drive the drive gears, which translate along the rack gears to move the platform upwardly or downwardly. The motor **320** is in communication with the controller **250** (FIG. **5**), which controls the vertical position of the platform. The platforms of the other heating zones can have a similar configuration.

FIG. **9** shows an alternative configuration for effecting vertical movement of a platform. In this embodiment, a platform **304** is mounted to four linear actuators **350** (one mounted at each corner of the platform), although a greater or fewer number of actuators can be used. Each actuator **350** in the illustrated embodiment comprises a threaded shaft **352** and a nut **354** disposed on the shaft. The platform **304** is supported on the upper ends of the shafts **352**. Synchronized rotation of the nuts **354** (controlled by the controller **350**) causes the platform **304** to be raised or lowered relative to the conveyor **230**. It should be noted that various other mechanisms can be used to effect vertical movement of the platforms. For example, any of various pneumatic, electromechanical, and/or hydraulic mechanisms can be used to move a platform upwardly and downwardly, including various types of linear actuators, screw motors, screw rails, and the like.

As can be appreciated, adjusting the vertical position of the heat source(s) on a platform adjusts the gap or spacing G between the heat source(s) and the product "P" supported on the support surface **230**. The temperature of the product varies according to the distance between the heat source and the product, as well as the temperature of the heat source. Increasing the distance from the heat source to the product will decrease the temperature of the product while decreasing the distance from the heat source to the product will increase the temperature of the product (if the temperature of the heat source remains constant). As noted above, the wavelength of radiant energy emitted from a heat source can be increased and decreased by decreasing and increasing, respectively, the temperature of the heat source. Accordingly, the temperature of the product "P" within a heating zone and the wavelength of radiant energy absorbed by the product within that heating zone can be independently controlled by adjusting the temperature of the heat source(s) and the distance between the heat source(s) and the product.

In particular embodiments, the controller **250** can be configured to continuously monitor the temperature of the product (and/or other characteristics of the product) via sensors **281**, **282**, **283** and the temperature of the heat sources via the thermocouples **314** and to automatically adjust the vertical position of the heat sources and/or the temperature of the heat sources to maintain a predetermined temperature profile for the product and a predetermined wavelength of radiant energy in each heating zone. In order to determine the wavelengths of radiant energy from the heat sources, the controller **250** can include an algorithm or look-up table that is used by the controller to determine the wavelength corresponding to each heat source based on the temperature readings of the thermocouples **314** that are relayed to the controller.

In one implementation, the wavelength of a heat source can be determined by measuring the temperature of the heat source and calculating the wavelength using Wien's law ($\lambda max=b/T$, where λmax is the peak wavelength, b is Wien's displacement constant and T is the temperature of the heat source). In another implementation, the wavelength of a heat source can be determined by measuring the temperature of the heat source and identifying the corresponding peak wavelength of the heat source on a graph, such as illustrated in FIG. **10**. Alternatively, the dryer can include wavelength sensors (as discussed above) that directly monitor the wavelengths of radiant energy from each heat source and relay signals to the controller.

The controller **250** can be in communication with a plurality of control devices **233** (FIG. **5**) that control the temperatures of the heating elements in each zone. Desirably, a control device **233** is provided for each zone of the dryer. For example, the control devices **233** can be solid state relays that modulate electric current to the heating elements by employing an "on/off" control scheme. More desirably, the control devices **233** comprise phase angle control modules that can increase or decrease the temperature of the heating elements by varying the voltage to the heating elements. Each phase angle control module **233** is in communication with the controller **250** and, based on signals received from the controller, varies the input voltage to the heating elements of a respective zone in order to raise or lower the operating temperature of the heating elements. The use of phase angle control modules **233** is advantageous in that it allows precise control over the operating temperatures of the heating elements in order to better achieve the desired product temperature profile.

The wavelength of infrared waves emitted from the heat sources in each zone can be selected based on the desired heating and drying characteristics for a particular product in a particular stage of drying as well as various product characteristics, such as the emissivity and the ability to absorb radiant heat. For example, the wavelength in each heating zone can be selected to maximize the radiant energy absorption rate in each heating zone for a particular product. FIG. **11** shows the absorption of electromagnetic radiation by water. In the infrared range, there is a peak at about 3 μm and at about 6.2 μm. In one specific implementation, it may be desirable to maintain a constant wavelength throughout the drying process at 3 or 6.2 μm for optimum absorption of the IR energy by the water in the product being evaporated. Because the moisture content of product applied to the support surface **230** varies as does the moisture in the product as it moves through each heating zone (as well as other product characteristics), the amount of heat required to achieve a desired product temperature in each zone can vary substantially. Consequently, the positions of the heat sources can be automatically adjusted to maintain a predetermined constant wavelength and a predetermined temperature profile. Moving the heaters produces a constant wavelength to compensate for changes in moisture content in the product during drying, and to compensate for different desired product temperature set-points in each drying zone (i.e., the desired drying temperature profile, which can vary for different products). In some cases it may be desirable to operate some heat sources at 3 μm in some drying zones (such as in the early zones where relatively higher temperatures are needed) and at 6.2 μm in other drying zones (such as in zones towards the end of the dryer where relatively lower temperatures are needed). In this manner, the specific wavelength (3 or 6.2 μm) for each zone can be selected based on whether the zone has any specific temperature limitations or requirements.

In other implementations, it may be desirable to change the wavelength in each successive zone for one or more reasons. For example, the emissivity of the product as a whole may change as it proceeds through the drying process. As such, the wavelength in each heating zone can be selected to maximize absorption of radiant energy by the product as the emissivity of the product changes during the drying process. As another example, the wavelength in each heating zone can be selected to achieve a desired degree of penetration of radiant waves into the product or to compensate for changes in thickness of the product layer as it dries. Moreover, the sensitivity of the product (or a particular compound in the product) to a particular wavelength of IR may increase as the product moves through the dryer. Thus, the wavelength in each heating zone can be selected to avoid damage to the product or particular compounds in the product.

The following describes one specific approach for operating the dryer **200**A to dry a product using a predetermined wavelength of IR. As noted above, infrared wavelengths of about 3 microns and 6.2 microns generally produce the best radiant energy absorption rate for water. Thus, the controller **250** can be programmed to control the temperature of the heat sources in each heating zone to produce infrared waves at, for example, 3 microns (or alternatively, 6.2 microns) across all heating zones. To maintain a predetermined temperature profile for the product, the controller **250** monitors the temperature of the product and continuously adjusts the spacing between the heat sources and the product as needed to maintain the desired temperature of the product within each zone. As discussed above, for drying certain products it is desirable to maintain a constant product temperature across zones Z**1**, Z**2**, Z**3**. Since the moisture content of the product decreases as the product moves through each zone, less heat is needed in each successive zone to maintain the desired product temperature. As such, the heat sources in the first control zone Z**1** typically are closer to the product than the heat sources in the second control zone Z**2**, which typically are closer to the product than the heat sources in the third control zone Z**3**, as depicted in FIG. **6**. As can be appreciated, the heat sources can operate at constant, or substantially constant operating temperatures, and the controller can cause the positions of the heat sources to move upwardly or downwardly to vary the amount of heat reaching the product. An advantage of operating the heat sources at constant or substantially constant operating temperatures is that the heat sources can be operated at constant or substantially constant power supply and voltage, which can significantly increase the energy efficiency of the dryer.

An alternative control scheme for operating drying apparatus **200**A is illustrated in the flowchart shown in FIG. **8** and can operate in the following manner. When the dryer is initially started and product is first applied to the support surface **230**, the heat sources are in a starting position (usually, but not necessarily, all of the heat sources are at the same vertical position). Referring to FIG. **8**, the controller first reads the product temperature (**402**) and adjusts the operating temperatures of the heat sources accordingly to achieve the desired product temperature in each heating zone (**404** and **406**). If the product temperature is at the predetermined set-point for the product in a particular zone, then the controller reads the operating temperature of the heat sources and determines the wavelength produced by the heat sources in that zone (**408** and **410**). Alternatively, the wavelength in the heating zone can be determined from signals relayed to the controller from a spectrometer, radiometer, or equivalent device.

If the wavelength in a particular zone is greater or less than a predetermined wavelength, the controller controls the heat sources in that zone to move farther away from or closer to the product (**412** and **414**). More specifically, if the measured wavelength is greater than the predetermined wavelength, then the controller causes the heat sources to move farther away from the product, and if the measured wavelength is less than the predetermined wavelength, then the controller causes the heat sources to move closer to the product. As the heat sources move farther away from or closer to the product, the product temperature may begin to decrease or increase, respectively. Consequently, the process loop starts over at block **402** where the controller reads the product temperature and increases or decreases the operating temperature of the heat sources until the predetermined product temperature is again achieved. At this point, the controller again determines the wavelength produced by the heat sources (**408** and **410**) and causes the heat sources to move even farther away from or closer to the product if the wavelength is still greater or less than the predetermined wavelength for that zone (**412** and **414**). This process loop is repeated until the heat sources produce energy at the predetermined wavelength. At this point, the controller again determines the product temperature (**402** and **404**), adjusts the operating temperature of the heat sources as needed to maintain the predetermined product temperature (**406**), and then compares the measured wavelength to the predetermined wavelength (**410** and **412**) and moves the heat sources if the measured wavelength is greater or less than the predetermined wavelength (**414**).

When the controller determines that the heat sources in a zone should be moved (either upwardly or downwardly), the heat sources can be moved in small, predetermined increments at block **414**. After each incremental movement, the controller reads the product temperature (**402**), increases or decreases the operating temperature of the heat sources to achieve the predetermined product temperature (**406**), and once the predetermined product temperature is achieved (**404**), the controller determines the wavelength produced by the heat sources (**408** and **410**), and then causes the heat sources to move another increment if the wavelength is longer or shorter than the predetermined wavelength (**414**).

The manner of operating the dryer illustrated in FIG. **8** can improve the responsiveness of the dryer (i.e., the ability of the system to increase or decrease the amount of heat applied to the product as needed to avoid overheating or underheating the product) compared to a control scheme where the heating elements are maintained at a constant temperature and are raised and lowered to adjust the amount of heat applied to the product. The method shown in FIG. **8** therefore includes two feedback loops, namely, a first feedback loop that adjusts the temperature of the heating elements in response to sudden changes that necessitate an immediate increase or decrease in the amount of heat applied to the product, and a second feedback loop that adjusts the positions of the heating elements until the targeted wavelength is achieved at the optimum product temperature. A variety of process characteristics vary during the drying process and can cause a demand for a sudden increase or decrease in the amount of heat that must be applied to the product in order to maintain the targeted temperature profile of the product. Some of these characteristics include the moisture and solids content of product applied to the conveyor, the initial product temperature, the rate and thickness of product applied to the conveyor, and ambient conditions (temperature and relative humidity). Operating two feedback loops in the manner described allows the operating temperatures of the heating elements to be increased and decreased quickly in order to respond to a demand for an increase or decrease in the amount of heat applied to the product so as to avoid overheating or underheating the product.

In another implementation, the controller **250** can be programmed to increase and decrease the temperature of a heat source within a predetermined temperature range that corresponds to an acceptable wavelength spectra prior to adjusting the position of the heat source. For example, the controller **250** can monitor product temperature and adjust the temperature of a heat source within a predetermined range as is needed to maintain the temperature profile. If the temperature of the heat source exceeds or drops below the predetermined range, the controller can then move the heat source closer to or farther away from the product as needed to maintain the temperature profile for the product. This manner of operating the dryer allows for very rapid responses from the heat sources to changes in the amount of heat required to achieve a desired product temperature in each drying zone. Explaining further, a target temperature is selected for each heater to achieve a desired wavelength, but in order to respond rapidly, the temperature of the heater is varied within a specified and limited range within an acceptable band of wavelengths. This allows the heat sources to respond rapidly to small, real time changes in in the product being dried, such as changes in moisture content or product thickness that may occur frequently, thereby avoiding overheating or underheating of the product.

In the illustrated embodiment, the controller **250** operates in a first feedback loop to control the temperature of the heat sources and in a second feedback loop to control the spacing of the heat sources relative to the product. In alternative embodiments, the temperature of the heat sources and their positions relative to the product can be manually adjusted by an operator. For example, the operator can monitor the various operating parameters of the process (product temperature, heat source temperature, etc.) and make adjustments to one or more of the operating parameters by inputting the information into the keypad **269**, which information is relayed to the controller **250**.

The drying apparatus **200**A in the illustrated embodiment is described in the context of drying a thin layer of liquid product. It should be understood that all of the embodiments of drying apparatus disclosed herein can be used to dry or otherwise apply heat to non-fluid food products (e.g., baked goods, rice) or any of various non-food products (e.g., wood products, sludge, film board, textiles, adhesives, inks, photosensitive layers, etc.).

EXAMPLE 1

Dehydrating Beet Juice Concentrate

Example 1 demonstrates the improved capacity that can be achieved by adjusting the position of the heaters relative to the product conveyor and the output of the heaters. In this example, a drying apparatus having 16 zones was used to dehydrate beet juice concentrate in a first drying run and a second drying run. The dehydrated beet juice concentrate was processed into powder form. Tables 1 and 2 show the zone settings of the dryer in the first and second runs, respectively. The heater distance in Tables 1 and 2 represents the distance between the heating elements and the conveyor in each zone. Table 3 show other dryer operating parameters and product characteristics for the first and second runs. The product set points across all zones (which determines the product temperature profile) were the same in each run. However, in the first drying run, the position of the heaters were manually adjusted prior to dryer operation in order to cause the heaters to emit infrared radiation at or around 6.2 μm (corresponding to peak "C" in FIG. **11**). In the second drying run, the position of the heaters were manually adjusted prior to dryer operation in order to cause the heaters to emit infrared radiation at or around 7.0 μm (corresponding to peak "D" in FIG. **11**). The wavelength of infrared radiation in each zone was determined by measuring the temperature of the heating elements and calculating the wavelength using Wien's law.

FIG. **12** shows the temperature of the heating elements in each zone of the dryer during the first drying run. FIG. **13** shows the temperature of the heating elements in each zone of the dryer during the second drying run. FIG. **14** shows the graphs of FIGS. **12** and **13** on one chart. FIG. **15** shows the measured wavelength of IR radiation in each zone for first and second drying runs.

Example 1 demonstrates that even with manually positioning of the heaters, the product temperature and wavelength of the heaters can be independently controlled. A much greater degree of precision in controlling the wavelength of infrared radiation across all zones can be achieved by continuous and automatic adjustment of temperatures of the heating elements and the position of the heating elements relative to the conveyor. Table 4 compares the throughput (drying capacity) and the energy usage of the two drying runs. It can be seen from the results of Table 4 that targeting 6.2 μm across all zones (drying run **1**) resulted in a 53% increase in drying capacity over targeting 7.0 μm across all zones (drying run **2**). Further, drying run **1** used less energy per kilogram of product dried than in drying run **2**, most likely because energy was more efficiently absorbed by the water in the product (which causes the product to release moisture).

Most importantly, Example 1 shows that an extremely high product quality can be achieved (as evidenced by the moisture content in both drying runs) by drying the product at the predetermined temperature profile while the drying capacity of the dryer can be increased substantially by operating the heating elements at a predetermined wavelength. In other words, the capacity of the dryer can be significantly improved by operating the heating elements at a predetermined infrared wavelength that maximizes the absorption of infrared radiation into the product, while also maintaining high product quality by precisely controlling the temperature of the product as it is dried. When dehydrating liquid food products, such as fruit or vegetable liquids, it is important to produce a high quality product that is low in moisture content (for improved flowability and shelf life) with minimal nutritional loss.

TABLE 1

Drying Run #1 - Zone Settings																
Zone	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Product set point temp. (° F.)	97	105	113	113	130	145	160	165	165	165	170	175	180	180	180	180
Heater Temp (F.)	366	367	363	382	287	313	321	321	356	328	340	345	329	326	325	325
Heater distance (in)	2.9	2.9	2.9	2.9	6.4	6.4	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9
Wavelength (um)	6.3	6.3	6.3	6.2	6.2	6.9	6.8	6.7	6.7	6.4	6.6	6.5	6.5	6.6	6.6	6.6

TABLE 2

Drying Run #2 - Zone Settings																
Zone	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Product set point temp. (° F.)	97	105	113	113	130	145	160	165	165	165	170	175	180	180	180	180
Heater Temp (F.)	464	260	307	204	301	280	300	304	301	317	299	301	305	327	308	305
Heater distance (in)	6.5	6.5	6.5	6.5	6.5	6.5	2.6	2.6	2.9	2.9	2.9	2.9	2.4	2.4	2.6	2.6
Wavelength (um)	5.6	7.2	6.8	7.9	7.0	7.0	7.0	6.8	7.0	6.7	6.9	7.0	6.8	6.6	6.8	6.8

TABLE 3

	Drying Run #1-Heaters Adjusted to Peak "C"	Drying Run #2-Heaters Adjusted to Peak "D"
Time	1 hour	1 hour
Ambient conditions	73.3 F., 45% RH	71.3 F., 51% RH
Initial product temp	41 F.	42 F.
Solids	45%	45%
Average water activity	.279	.273
Average moisture at 104 F.	1.12%	1.23%
Average moisture at 90 F.	0.69%	0.80%
Average product thickness (mm)	0.08	0.08
Throughput (kg/hr)	25.6	16.7
Total power (KVA)	154.4	126
Power per kg product (KVA/kg)	6.0	7.5

TABLE 4

Results Summary for Beet Juice Concentrate			
Drying run (beet juice concentrate)	Target Wavelength	Throughput (kg/hr)	Energy (KVA) used per kg of product
1	Peak "C" (about 6.2 μm)	25.6	6.0
2	Peak "D" (about 7-8 μm)	16.7	7.5

EXAMPLE 2

Dehydrating Fruit Puree Blend

In Example 2, a 16-zone dryer was used to dry a fruit puree blend comprising a mixture of grape puree and blueberry puree. The fruit puree blend was dried in four separate drying runs all having the same product temperature set points. The dehydrated fruit puree blend was processed into powder form. The first drying run (zone settings shown in Table 5) represents "baseline" operating conditions where the heating elements across all zones are set at the same distance from the conveyor. In the second drying run (zone settings shown in Table 6), the position of the heaters were kept the same as in drying run **1** but the rate of product applied to the conveyor was increased to increase the capacity of the dryer. In the third drying run (zone settings shown in Table 7), the position of the heaters were manually adjusted prior to dryer operation in order to cause the heaters to emit infrared radiation at or around 6.2 μm (corresponding to peak "C" in FIG. **11**). In the fourth drying run (zone settings shown in Table 8), the position of the heaters were manually adjusted prior to dryer operation in order to cause the heaters to emit infrared radiation at or around 7.0 μm (corresponding to peak "D" in FIG. **11**). The wavelength of infrared radiation in each zone was determined by measuring the temperature of the heating elements and calculating the wavelength using Wien's law. Table 9 summarizes other operating parameters and characteristics of the product for all four drying runs.

FIGS. **16**, **17**, **18**, and **19** show the temperature of the heating elements in all zones of the dryer for the first, second, third, and fourth drying runs, respectively. FIG. **20** shows the line graphs of FIGS. **16-19** on one chart. FIG. **21** shows wavelength of IR radiation measured in each zone for all four drying runs.

Table 10 compares the throughput (drying capacity) and the energy usage of all four drying runs. It can be seen from the results of Table 10 that targeting 6.2 μm across all zones (drying run **3**) resulted in a 55% increase in drying capacity over the second drying run where the position of the heaters were not adjusted. Drying run **3** also provided the lowest energy consumption per kilogram product dried.

Like Example 1, Example 2 shows that an extremely high product quality can be achieved (as evidenced by the moisture content in all drying runs) by drying the product at the predetermined temperature profile while the drying capacity of the dryer can be increased substantially by operating the heating elements at a predetermined wavelength.

TABLE 5

Fruit Puree Blend - Baseline																
Zone	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Product Set Temp (F.)	110	125	135	145	145	155	165	165	175	175	180	185	185	185	185	185
Avg Heater Temp (F)	379	471	454	311	337	286	313	303	317	335	335	317	333	333	317	330
Heater distance (in)	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
Wavelength	6.2	5.6	5.7	6.8	6.6	7.0	6.7	6.8	6.7	6.6	6.6	6.7	6.6	6.6	6.7	6.6

TABLE 6

Fruit Puree Blend - High Throughput, no Heater Adjustment																
Zone	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Product Set Temp (F.)	110	125	135	145	145	155	165	165	175	175	180	185	185	185	185	185
Avg Heater Temp (F.)	418	463	460	420	407.7	309	328	340	336	368	363	332	352	343	331	333
Heater distance (in)	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
Wavelength	5.9	5.7	5.7	5.9	6.0	6.8	6.6	6.5	6.6	6.3	6.3	6.6	6.4	6.5	6.6	6.6

TABLE 7

Fruit Puree Blend - High Throughput, Heaters Adjusted to Peak "C"																
Zone	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Product Set Temp (F.)	110	125	135	145	145	155	165	165	175	175	180	185	185	185	185	185
Avg Heater Temp (F.)	314	478	429	421	486	365	408	385	374	382	386	330	364	347	333	339
Heater distance (in)	2.9	2.9	2.4	2.4	2.9	2.9	8.9	8.9	8.9	8.9	8.9	8.9	8.4	8.4	8.4	8.4
Wavelength	6.7	5.6	5.9	5.9	5.5	6.3	6.0	6.2	6.3	6.2	6.2	6.6	6.3	6.5	6.6	6.5

TABLE 8

Fruit Puree Blend - High Throughput, Heaters Adjusted to Peak "D"								
Zone	1	2	3	4	5	6	7	8
Product Set Temp (F.)	110	125	135	145	145	155	165	165
Avg Heater Temp (F.)	463	324	376	421	466	350	318	317
Heater distance (in)	7.75	7.75	8.75	8.75	8.75	8.75	2.625	2.625
Wavelength	5.7	6.7	6.2	5.9	5.6	6.4	6.7	6.7

TABLE 8-continued

Fruit Puree Blend - High Throughput, Heaters Adjusted to Peak "D"								
Zone	9	10	11	12	13	14	15	16
Product Set Temp (F.)	175	175	180	185	185	185	185	185
Avg Heater Temp (F.)	324	345	343	326	334	331	326	322
Heater distance (in)	2.875	2.875	2.375	2.375	2.375	2.375	2.625	2.625
Wavelength	6.7	6.5	6.5	6.6	6.6	6.6	6.6	6.7

TABLE 9

	Drying Run #1-Baseline	Drying Run #2-High Throughput	Drying Run #3-High Throughput, Heaters Adjusted to Peak "C	Drying Run #4-High Throughput, Heaters Adjusted to Peak "D"
Time	1 hour	1 hour	1 hour	1 hour
Ambient conditions	68.5 F., 45% RH	68.5 F., 45% RH	68.5 F., 45% RH	68.5 F., 45% RH
Initial product temp	41 F.	41 F.	41 F.	41 F.
Solids	30%	30%	30%	30%
Average water activity	.324	.328	.346	.343
Average moisture at 104 F.	2.30%	2.47%	2.91%	2.36%
Average moisture at 90 F.	0.99%	1.64%	1.61%	1.13%
Average product thickness (mm)	0.13	0.17	0.18	0.17
Throughput (kg/hr)	15.8	18.8	29.1	20.4
Total power (KVA)	193.1	181	198	170
Power per kg product (KVA/kg)	12.2	9.6	6.8	8.4

TABLE 10

Results Summary for Fruit Puree Blend			
Drying run (fruit puree blend)	Target Wavelength	Throughput (kg/hr)	Energy (KVA) used per kg of product
Run 1 - Baseline	None	15.8	12.2
Run 2 - High Throughput	None	18.8	9.6
Run 3 - High Throughput, Heaters Adjusted to Peak "C"	Peak "C" (about 6.2 μm)	29.1	6.8
Run 4 - High Throughput, Heaters Adjusted to Peak "D"	Peak "D" (about 7-8 μm)	20.4	8.4

The following factors can affect a dryer's ability to control the wavelength and product temperature within a control zone: (i) the range of adjustment of heating elements towards and away from the support surface of the conveyor belt; (ii) the watt density of the heating elements; (iii) spacing between heating elements; and (iv) the reflector configuration of the heating elements. These features can be optimized within each control zone to maximize dryer capacity and product quality.

If a heating element is too close to the conveyor (e.g., closer than the spacing between individual heating elements), hot/cold areas on the conveyor belt can result if the radius of infrared beams from adjacent heating elements do not overlap as the infrared energy is projected onto the belt. Thus, the minimum distance between the heating elements and the conveyor should be at least equal to or greater than the spacing between individual heating elements. A heating element that is too far away from the conveyor belt will require a relatively high amount of energy to achieve the product temperature at a given wavelength due to the fact that energy density decreases as the square of the distance between the heating element and the conveyor.

The watt density of a heating element can be expressed in watts per inch of the length of the heating element. If the watt density of a heating element is too high, then the heating elements will have to be located very far from the belt to maintain a heater temperature to emit the desired wavelength for a given product temperature. If the watt density of a heating element is too low, then the heating element may need to be too close to the belt, creating hot and cold spots and/or the heating element may not achieve the heater temperature required to achieve the desired wavelength. In order to account for changes in moisture content of the product during drying, the heater watt density and spacing between individual heating elements can be selected based on the moisture content range anticipated in a particular zone, and the anticipated wattage required based on the thermal capacity of the product ($Q=mCp(T1-T2)$) as well as the amount of water vapor produced (1000 BTU/lb. of steam).

Quartz heaters can be clear or frosted and can include a reflector directly on the element or some distance behind the element. For example, each heater support **302**, **304**, **306**, **308** (FIG. **6**) can include a reflector (e.g., a metal pan) positioned below the heating elements supported by the heater support.

Heating elements with a reflector on the element itself will have a relatively higher element temperature at the same conditions due to reflection of the bottom infrared directly back at the element itself, resulting in a higher temperature and shorter wavelength at the same power setting compared to a heating element that has a reflector that is positioned below the heating element. If the reflector is below the heating element, more of the initial infrared waves can be reflected around the element. The advantage of reflecting around the element is that there can be a more even distribution of infrared onto the belt, especially in a zone where the heating elements are relatively close to the belt due high removal rate of water (high heat of vaporization). On the other hand, reflectors on the heating elements would be more favorable in control zones where the heaters need to be relatively further away from the belt so as to reduce the maximum distance of the heating elements from the belt, thereby reducing the amount of energy required to achieve the desired wavelength.

The selection of heater adjustment range, watt density, heater spacing, and reflector configuration can be further explained with reference to FIG. **22**. FIG. **22** shows a schematic illustration of a dryer **500** for drying fruit and vegetable liquids (although it can be used for drying other substances). The dryer **500** comprises five main dryer sections **502**, **504**, **506**, **508**, and **510**. Each dryer section can include one or more control zones. Typically, each control zone comprises a plurality of infrared heating elements (also referred to as infrared emitters or infrared lamps). Within each dryer section, there can be movable heater supports (e.g., 302, 304, 306, 308) that support the heating elements of one control zone, heater supports that support the heating elements of more than one control zone, or a combination of heater supports that support the heating elements of one control zone and heater supports that support the heating elements of more than one control zone. The length of the control zones (in the direction of movement of the conveyor) as well as the length of the movable heater supports can vary along the length of the dryer, for example between one foot and 10 feet. Generally speaking, shorter control zones and shorter heater supports can provide more precise control over product temperature and can be more responsive to changes in thermal properties of the product due to loss of moisture. In particular embodiments, the first dryer section **502** extends about 10% of the overall dryer length; the second dryer section **504** extends about 25% of the overall dryer length; the third dryer section **506** extends about 35% of the overall dryer length; the fourth dryer section **508** extends about 20% of the overall dryer length; and the fifth dryer section **510** extends about 10% of the overall dryer length.

The first dryer section **502** is a "ramp-up" section of the dryer in which the product temperature is increased in a short amount of time to an optimum temperature for most efficient evaporation for the product. In this dryer section, the control zones can be relatively short to increase the product temperature as quickly as possible while avoiding overheating. In particular embodiments, the watt density of the heating elements in this dryer section are in the range of about 20-80 watts/inch, with 50 watts/inch being a specific example. Heater spacing (distance between individual heating elements) is in the range of about 0.5 inch to about 5.0 inch, with 2.0 inch being a specific example. The length of each control zone is in the range of about 6 inches to about 60 inches, with 30 inches being a specific example (each zone having about 15 heating elements). The length of each movable heater support is in the range of about 6 inches to about 60 inches, with 30 inches being a specific example. In a specific implementation, each movable heater support can support the heating elements of one control zone (such as shown in FIG. **6**). The distance between the heating elements and the conveyor **230** within the first dryer section **502** can be adjusted between about 0.5 inch and 5.0 inches, with 2.0 inches being a specific operating distance. Reflectors mounted below the heating elements can be used in this dryer section.

The second dryer section **504** is a high evaporation section in which the moisture content is initially high, and the product is maintained at an efficient temperature for moisture evaporation. In this section, the process is generally at a steady state evaporating a large amount of moisture with little effect on product temperature. Accordingly, the control zones can be relatively longer in this dryer section. A relatively large amount of energy is required in this dryer section. In particular embodiments, the watt density of the heating elements in this dryer section are in the range of about 20-80 watts/inch, with 60 watts/inch being a specific example. Heater spacing (distance between individual heating elements) is in the range of about 0.5 inch to about 5.0 inch, with 2.0 inch being a specific example. The length of each control zone is in the range of about 15 inches to about 120 inches, with 60 inches being a specific example (each zone having about 30 heating elements). The length of each movable heater support is in the range of about 15 inches to about 240 inches, with 120 inches being a specific example. In a specific implementation, each movable heater support can support the heating elements of two control zones. The distance between the heating elements and the conveyor **230** within the second dryer section **504** can be adjusted between about 0.5 inch and 5.0 inches, with 2.0 inches being a specific operating distance. Reflectors mounted below the heating elements can be used in this dryer section.

The third dryer section **506** is a transition section in which the product transitions into a mostly dry state and becomes very heat sensitive. Accordingly, the lengths of the control zones desirably are relatively shorter in this dryer section to respond to any fluctuations in product characteristics that affect the drying rate. In particular embodiments, the watt density of the heating elements in this dryer section are in the range of about 20-60 watts/inch, with 30 watts/inch being a specific example. Heater spacing (distance between individual heating elements) is in the range of about 0.5 inch to about 24.0 inch, with 3.0 inch being a specific example. The length of each control zone is in the range of about 15 inches to about 120 inches, with 30 inches being a specific example (each zone having about 10 heating elements). The length of each movable heater support is in the range of about 15 inches to about 240 inches, with 30 inches being a specific example. In a specific implementation, each movable heater support can support the heating elements of one control zone. The distance between the heating elements and the conveyor **230** within the third dryer section **506** can be adjusted between about 0.5 inch and 24.0 inches, and more specifically between about 4.0 inches to about 10 inches. In this drying section, a combination of reflectors mounted below the heating elements and heating elements having integral reflectors can be used.

The fourth drying section **508** is a final drying section where the product initially is mostly dry and the control zones are relatively longer to remove the last moisture from the product under relatively steady state conditions. Longer control zones are desirable to maintain substantially constant drying. In particular embodiments, the watt density of the heating elements in this dryer section are in the range of about 20-80 watts/inch, with 60 watts/inch being a specific example. Heater spacing (distance between individual heating elements) is in the range of about 0.5 inch to about 5.0 inch, with 4.0 inch being a specific example. The length of each control zone is in the range of about 60 inches to about 120 inches, with 90 inches being a specific example (each zone having about 22 heating elements). The length of each movable heater support is in the range of about 15 inches to about 240 inches, with 120 inches being a specific example. In a specific implementation, some of the movable heater supports can support the heating elements of one control zone while other movable heater supports can support the heating elements of two control zones. The distance between the heating elements and the conveyor **230** within the fourth dryer section **508** can be adjusted between about 0.5 inch and 20.0 inches, with 16 inches being a specific operating distance. Heating elements having integral reflectors can be used in this drying section.

The fifth drying section **510** is an exit or "ramp-down" section where the control zones can be relatively short to reduce the product temperature for annealing and/or to avoid overheating a particularly heat sensitive product. In particular embodiments, the watt density of the heating elements in this dryer section are about 10 watts/inch. Heater spacing (distance between individual heating elements) is in the range of about 0.5 inch to about 5.0 inch, with 3.0 inch being a specific example. The length of each control zone is in the range of about 60 inches to about 120 inches, with 30 inches being a specific example (each zone having about 10 heating elements). The length of each movable heater support is in the range of about 15 inches to about 120 inches, with 30 inches being a specific example. In a specific implementation, each movable heater support can support the heating elements of one control zone. The distance between the heating elements and the conveyor **230** within the fifth dryer section **510** can be adjusted between about 0.5 inch and 15.0 inches, with 10 inches being a specific operating distance. Heating elements having integral reflectors can be used in this drying section.

In a specific implementation, a dryer **500** has an overall length of about 100 feet. The first dryer section **502** has four control zones, each of which is about 30 inches in length and is mounted on a respective movable heater support. The second dryer section **504** has five control zones, each of which is about 60 inches in length, and ten movable heater supports, each supporting two control zones. The third dryer section **506** has fourteen control zones, each of which is about 30 inches in length and is mounted on a respective movable heater support. The fourth dryer section **508** has three control zones, each of which is about 90 inches in length. The fourth dryer section **508** can include movable heater supports that support one control zone and heater supports that support more than one control zone. The fifth dryer section **510** has four control zones, each of which is about 30 inches in length and is mounted on a respective movable heater support.

In view of the many possible embodiments to which the principles of the disclosed invention may be applied, it should be recognized that the illustrated embodiments are only preferred examples of the invention and should not be taken as limiting the scope of the invention. Rather, the scope of the invention is defined by the following claims. We therefore claim as our invention all that comes within the scope and spirit of these claims.

I claim:

1. A drying apparatus comprising:

a movable product conveyor having a product support surface for supporting a product to be dried;

at least first and second heater supports, each heater support supporting one or more dry radiant heating elements and being movable relative to each other and relative to the conveyor to adjust the distance between each heater support and the conveyor;

the product conveyor being configured to move relative to the first and second heater supports such that the product supported on the conveyor is successively heated by the heating elements of the first heater support and the heating elements of the second heater supports; and

a controller configured to adjust the temperature of the heating elements of each heater support and the distance between the heating elements of each heater support and the conveyor such that the heating elements emit radiant heat at a predetermined wavelength and heat the product according to a predetermined product temperature profile,

wherein the controller is configured to operate in first and second feedback loops, such that in the first feedback loop, the controller monitors the temperature of the product and adjusts the temperature of the heating elements, and in the second feedback loop, the controller monitors the wavelength of the heating elements and adjusts the distance between the heating elements and the conveyor such that the heating elements heat the product according to the predetermined product temperature profile and maintain the predetermined wavelength;

a plurality of temperature sensors positioned to measure the temperature of the heating elements of each heater support, the controller being in communication with the temperature sensors and being configured to determine the wavelength of radiant heat emitted by the heating elements based on their temperature.

2. The drying apparatus of claim **1**, wherein the controller comprises at least a first phase angle control device that controls the temperature of the heating elements of the first heater support and a second phase angle control device that controls the temperature of the heating elements of the second heater support.

3. The drying apparatus of claim **1**, wherein each heater support is supported by a plurality of upright support posts and is movable upwardly and downwardly relative to the support posts.

4. The drying apparatus of claim **3**, wherein each heater support comprises at least one drive mechanism that causes the heater support to move upwardly and downwardly relative to the support posts.

5. The drying apparatus of claim **1**, wherein the heater supports are located below the product support surface and are movable upwardly and downwardly toward and away from the product support surface.

6. The drying apparatus of claim **1**, wherein the controller is configured to adjust the temperature of the heating elements of each heater support and the distance between the heating elements of each heater support and the conveyor such that the product adsorbs radiant heat at a substantially constant wavelength as it is conveyed past the heating elements of the first and second heater supports.

7. The drying apparatus of claim **1**, further comprising a plurality of temperature sensors positioned to measure the temperature of the product being heated by the heating elements, the controller being in communication with the temperature sensors and being configured to adjust the temperature of the heating elements based on feedback from the temperature sensors to maintain the predetermined product temperature profile.

8. A method of drying a product, comprising:

applying a product to be dried onto a product support surface of a movable conveyor;

conveying the product on the conveyor through at least a first heating zone and a second heating zone;

heating the product with a first set of one or more dry radiant heating elements in the first heating zone and heating the product with a second set of one or more dry radiant heating elements in the second heating zone;

as the conveyor conveys the product through the first and second heating zones, adjusting the temperature of the heating elements and the distance between each set of heating elements and the product support surface to heat the product at a predetermined temperature profile and to cause the heating elements to emit radiant heat at a predetermined wavelength; and

measuring the temperature of the product in the first and second heating zones, determining the wavelength of the radiant heat emitted by the heating elements in the first and second heating zones, and adjusting the temperature of the heating elements and the distance between each set of heating elements and the product support surface based on the measured temperatures and the determined wavelengths so as to heat the product at the predetermined temperature profile and to cause the heating elements to emit radiant heat at the predetermined wavelength;

wherein determining the wavelength of the radiant heat emitted by the heating elements in the first and second heating zones comprises measuring the temperature of the heating elements in the first and second heating zones and determining the wavelength of the radiant heat in the first and second heating zones based on the measured temperatures of the heating elements.

9. The method of claim **8**, wherein the heating elements are located below the product support surface and the act of adjusting the distance between each set of heating elements and the product support surface comprises moving each set of heating elements upwardly or downwardly relative to the product support surface.

10. The method of claim **8**, wherein the temperature of the heating elements and the distance between each set of heating elements and the product support surface are adjusted to maintain a substantially constant product temperature in the first and second heating zones and such that wavelength of radiant heat emitted in the first and second heating zones is substantially constant.

11. The method of claim **8**, wherein the temperature of the heating elements and the distance between each set of heating elements and the product support surface are adjusted such that the product temperature in the second heating zone is greater than in the first heating zone and such that wavelength of radiant heat emitted in the first and second heating zones is substantially constant.

12. The method of claim **8**, wherein the heating elements in the first and second heating zones emit infrared radiation at about 3 μm.

13. The method of claim **8**, wherein the heating elements in the first and second heating zones emit infrared radiation at about 6.2 μm.

14. The method of claim **8**, wherein the temperature of the heating elements in each zone is adjusted by controlling a phase angle control device that modulates the amount of electrical energy supplied to the heating elements.

15. The method of claim **8**, wherein the product comprises a fruit or vegetable liquid and the act of heating the product comprises substantially dehydrating the fruit or vegetable liquid.

16. The method of claim **15**, further comprising processing the dehydrated fruit or vegetable liquid into a powder.

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